STATE COLLEGE OF AGRICULTURE AND APPLIED SCIENCE
LIBRARY
JAN 9 1947
MANHATTAN KANSAS

ECONOMIC GEOLOGY

AND THE

BULLETIN OF THE SOCIETY OF
ECONOMIC GEOLOGISTS

VOL. XLI DECEMBER, 1946 No. 8

QUARTZ CRYSTAL DEPOSITS IN THE STATE OF GOIAZ, BRAZIL.

DONALD F. CAMPBELL.[1]

CONTENTS.

	PAGE
Introduction	773
Geography and General Geology	775
Crystal Deposits	776
Secondary deposits	776
Bedrock deposits	776
Methods of mining and prospecting	777
Labor	777
Commercial aspects	777
Future possibilities	779
Cristalina District	779
Cavalcante-Tocantins District	782
Northcentral Goiaz District	790
Conclusions Regarding Formation of Deposits	798

ABSTRACT.

The three major quartz crystal producing regions in the state of Goiaz were examined as part of the field studies of the Quartz Commodity Program of the Foreign Economic Administration. Their principal geologic features are summarized.

The crystal deposits are situated in the thinly settled country of the Central Brazilian Plateau; transportation is difficult and living conditions are unsatisfactory due mainly to the isolation of the districts.

Quartz crystal of commercial quality occurs as a minor constituent of quartz veins cutting Algonkian quartzites and Archean schists. Important production has been won from secondary deposits formed by weathering and erosion of the vein outcrops. Large inferred reserves of quartz crystal exist in Northcentral and Eastcentral Goiaz.

Mining is by primitive methods. Numerous speculators and ore buyers handle the material between the mines and the port of export.

INTRODUCTION.

THERE are three major crystal producing districts in the State of Goiaz. In order of importance, based on past production, they are: Cristalina, Caval-

[1] Published by permission of the former Director of Metals and Minerals, Foreign Economic Administration, Washington, D. C.

cante-Tocantins, and Northcentral Goiaz (Fig. 1). In the future, Northcentral Goiaz will be the most important. Occasional crystal has been produced in Cristalina since the last century. Mining has been in progress there and in Cavalcante-Tocantins more or less continuously since about 1920; crystal production was begun in Northcentral Goiaz in 1942.

Total production from Goiaz is estimated at approximately 3,000 metric tons of commercial [2] crystal of which about 56 per cent came from Cristalina, 28 per cent from Cavalcante-Tocantins, and 16 per cent from North-Central

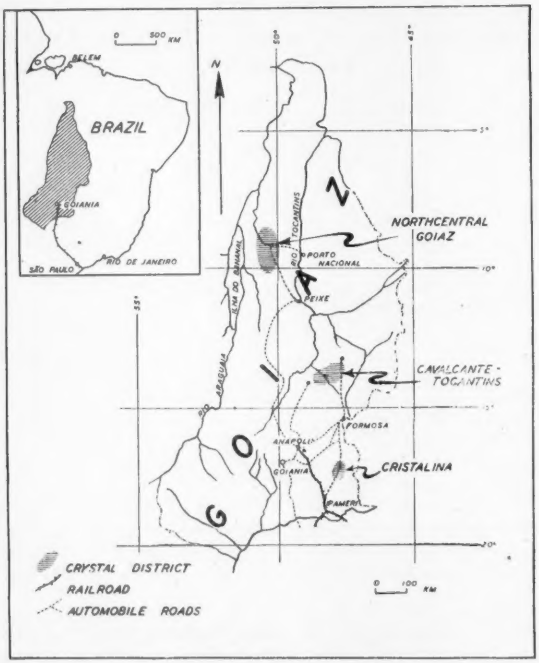


FIG. 1. Map showing location crystal districts, state of Goiaz, Brazil.

[2] Commercial crystal as used in this report is clear material, greater than 100 grams in size of individual stones, and which appears to be sufficiently valuable to miner or buyer to warrant removal from mines and transport to export centers. As ordinarily interpreted commercial crystal at mines is free from large or obvious defects in its structure. Upon detailed examination small scale defects and twinning are common in much of the clear crystal which is classified as commercial at the mines. The result is that after close examination anywhere between 5 per cent and 95 per cent of the mine production is of export quality. This percentage of course would depend upon the character of the quartz in the individual mine, the degree of beneficiation or trimming given to each stone at the mine, and the skill of the classifier. The factor between commercial crystal (mine clean) at the mines and export grade material according to the classification by the U. S. Commercial Company based upon specifications of the National Bureau of Standards has been estimated at 50 per cent.

Goiaz. Maximum production came in 1942 and 1943 as a result of the large war-time demand. It is estimated that approximately half of the total production was obtained during those two years. Production declined rapidly during 1945 due to slackened demand and exhaustion of some of the deposits.

Field work by the writer took place between July and October 1945, while attached to the Quartz Program of the Foreign Economic Administration, in cooperation with J. W. Malinowsky, in charge of the Goiaz area. Part of the field work in Goiaz was done in company of W. D. Johnston, Jr. and Earl Ingerson; some of the conclusions presented herein are the result of joint work and discussion.

A general paper on the quartz deposits of Brazil, by Johnston and Butler (4) is awaiting publication in the Bulletin of the Geological Society of America. This paper supplements and amplifies the data on the Goiaz deposits therein given.

The writer is indebted to W. D. Johnston, Jr., for continued aid and supplementary data on mines in Cristalina (1); as some were inaccessible during 1945. Robert D. Butler, Chief of the Quartz Program in Brazil for the Foreign Economic Administration furnished suggestions and read the manuscript. Prof. B. S. Butler, head of the Geology Department at the University of Arizona, read the manuscript. Permission for publication was granted by Alan M. Bateman, Director of Metals and Minerals, Foreign Economic Administration, Washington, D. C.

GEOGRAPHY AND GENERAL GEOLOGY.

The State of Goiaz is located in the central part of Brazil between 5° and 20° south latitude (Fig. 1). Goiânia, the capital, is approximately 1,000 km. (625 miles) northwest of Rio de Janeiro. Goiaz lies on the central plateau region of Brazil, and has a general elevation of 1,200 meters (3,937 ft.) in south-central and eastern parts but this elevation decreases both to the north and the south. In the Northcentral Goiaz Crystal District the elevation is but 250 meters (820 ft.).

A few low ranges project above the plateau level but in general interstream areas are broad and have low relief. Intrenched meanders along the main streams are evidently a product of recent uplift. Valley bottoms are wide and the slopes have a flat "V" cross section.

Approximately the northern three-quarters of Goiaz lies in the Amazon drainage basin, with the northward flowing Tocantins and Araguaia rivers being the master streams. The southern quarter of Goiaz is in the La Plata drainage basin, with the tributaries of the Paraná River being the main streams.

Transportation in Goiaz is difficult and expensive, whatever means is utilized. The state is served by several airlines—from Rio de Janeiro, São Paulo, and Belem.

The country rocks of the Goiaz crystal deposits are quartzite and schist. The Cristalina and Cavalcante-Tocantins districts are in the north-south trending belt of Algonkian rocks, a conspicuous geologic feature of eastern

Goiaz (2). The rock in the mine areas is a flat-lying to gently dipping fine-grained quartzite. It is medium gray in color with beds ranging in thickness up to 0.4 meters; some show cross-bedding. Along mineralized zones, cementing material and coloring matter have been leached from the quartzites resulting in soft light-gray to white sandstone. The schistose rocks of the Northcentral Goiaz district are shown as Cretaceous in age on the geologic map of Brazil (2) but were later classified as Algonkian by Shearer and de Souza (3). All the deposits examined in the Piaus-Itaporé area occur in weathered mica schists that closely resemble the Archean schists of Minas Gerais.

CRYSTAL DEPOSITS.

Crystal of commercial quality occurs as a minor constituent associated with bodies of coarse grained quartz. Erosion of the quartz bodies has resulted in the formation of secondary deposits of crystal-bearing gravels.

Secondary Deposits.—Secondary deposits are found over and around outcrops of quartz and also in areas where primary deposits are not visible. They are chiefly of the eluvial type but alluvial gravels are locally important. In eluvial deposits commercial crystal occurs in a rubble of quartz fragments with which a little soil is mixed. The fragments may range in size from a few millimeters to a meter or more in diameter, and the commercial crystal is usually an exceedingly small proportion of the total quartz. In alluvial deposits the crystal occurs in a gravel layer, generally on bedrock, under a cover of soil up to several meters thick. In some cases there appears to be some gradation between eluvial and alluvial types.

Secondary deposits are locally more extensive than bedrock deposits due to (1) downslope creep and wash as the quartz outcrops were eroded, and (2) to residual concentration during which some of the primary quartz bodies were almost completely eroded away. Because of freedom from cracks, pieces of commercial crystal are more resistant to weathering and erosion than non-commercial quartz and vastly more resistant than crystal aggregates. Some crystal from secondary deposits is rounded and frosted, and is locally referred to as "ovos de ema" (ostrich eggs) or as "rolado" (rolled). In Goiaz, secondary deposits have been more productive and commercially profitable than bedrock deposits. Most of the future production from known mines will come from bedrock deposits, while the initial production from new discoveries will probably come chiefly from secondary deposits.

Bedrock Deposits.—Bedrock deposits consist of milky coarse-grained quartz enclosed in schist or quartzite beneath a variable depth of overburden which may or may not contain detrital or residual material. In form these quartz bodies range from veinlets to irregularly shaped masses and chimneys of 20 to 30 meters diameter. The typical forms are crosscutting veins, irregular masses and pods lying in the bedding of the quartzites, and irregular masses or chimneys cutting schists. The outcrops, in places, suggest a large scale stockwork composed of individual members that are extremely irregular in shape, attitude, and distribution.

Clear crystal of commercial grade is associated with clay and iron and

manganese oxides in or near the larger masses of milky quartz. The clear crystal is mostly a vug filling and is intimately associated with well-formed non-commercial crystal. The ratio between commercial quartz and total quartz is low but Johnston estimated 1 : 500 for one of the mines at Cristalina. This value appears to be much higher than the average for Brazil which is probably in the range of one part to several thousand.

Methods of Mining and Prospecting.—In various mines, the material handled is composed of:

In Hardrock Mines

A. Soil and gravel
B. The ore
  1) Massive quartz
  2) Crystal (well-formed)
    a. Defective (cloudy or fractured)
    b. Commercial (clear)
      i) Non-exportable
      ii) Export grade
C. Country rock

In Eluvial and Alluvial Mines

A. Soil (may be thin or lacking)
B. The ore
  1) Clay and gravel
  2) Quartz cobbles
    a. Defective
    b. Commercial (clear)
      i) Non-exportable
      ii) Export grade

The percentage of commercial crystal in any deposit is exceedingly small.

Crystal mining in Goiaz is exceedingly primitive; practically all of it is worked by hand from open cuts. In the Cristalina and Cavalcante-Tocantins districts waste is removed from the open cuts by relay shovelling up the benched sides of the pits. In Northcentral Goiaz the common method of working deeper pits is to hoist waste by windlass (Fig. 4A) or man-whim, and carry it to the dumps. Depths of approximately 20 meters have been reached in each of the districts. Water is removed from the pits by bailing and pumping; small gasoline powered pumps are in general use in Cristalina and Northcentral Goiaz (Fig. 2A). During the wet season (November to April) work in the deeper pits becomes difficult or impossible because of the large volume of water and caving of the sides of the pits.

Prospecting consists chiefly of looking for crystal in the quartz surface float. In the Cristalina District steel bars are in general use for prodding to locate quartz gravel under soil cover. In general, however, no systematic exploration has been done, especially in areas at some distance from known deposits.

Labor.—Mining is the chief activity in the Goiaz crystal districts. The industry depends for its labor supply upon nomadic miners, or "garimpeiros." They have a low standard of living and a tendency to drift from one discovery to another and to other types of mining such as gold or diamonds. The isolation of the mining districts and the fact that the miners are not inclined to raise their own food makes the food supply a serious and expensive problem. Furnishing food is the common method of attracting and holding labor; all operators must feed their men. In the primitive system of mining in general use, production increases resulted through an increase in the labor supply.

Commercial Aspects.—The outstanding characteristic of the crystal mining

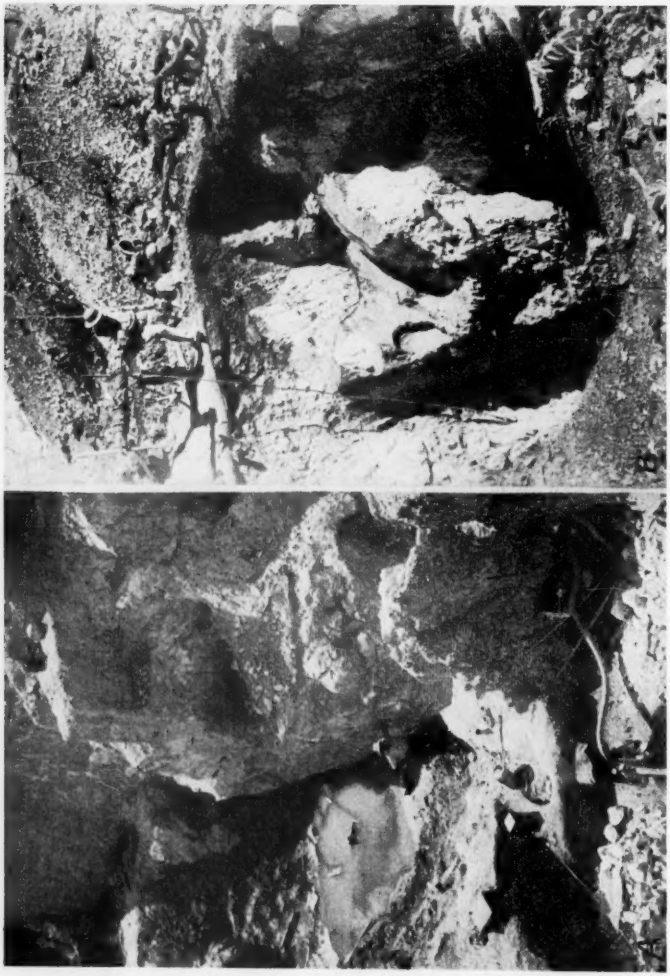


FIG. 2 A. Quartz body in the Pedreira Pit, Piaus mine area, Northcentral Goiaz District. The man is leaning against one of the planes which bounds the quartz. Commercial crystal occurred in pockets alongside the massive quartz. Water is removed by gasoline powered centrifugal pumps.

FIG. 2 B. Massive quartz body, Manchão Felipé, Itaporé area, Northcentral Goiaz District. Such quartz bodies are being explored in search of nests which carry such commercial quartz.

industry in Goiaz, as elsewhere in Brazil, is the large number of middle men, ore buyers and speculators, between the miner and the export point. The profits of the industry have largely gone to the middle men; the miners earned the necessities for existence.

Crystal exporting firms in Rio de Janeiro at intervals send representatives to the crystal districts. These representatives in turn maintain buyers in the producing centers to accumulate crystal through the purchases of small lots from other buyers and miners. A piece of crystal may be bought and sold half a dozen times or more before it finally reaches the exporter in Rio de Janeiro.

At each stage of progress towards the port, grading of the crystal according to quality and size becomes more exigent. Transactions at the mines are usually on the basis of the contained proportion of material free from defects visible to the naked eye. Cracks and larger inclusions may be distinguished by the naked eye in ordinary light. Later transactions are frequently on the basis of grading under a strong beam of light, such as an arc lamp beam. This examination reveals smaller inclusions not visible in ordinary light. Final grading before exportation may be done in Rio de Janeiro by use of arc lamp, oil bath, and polariscope to detect optical twinning.

Mining in the past has been chiefly done by many small more or less independent operators (garimpeiro system); the deposits lend themselves readily to this system of mining. At present, because of the exhaustion of many of the known deposits and increasing depth of the workings, the trend is toward fewer and larger operations in which the miner is paid a daily wage and board.

Future Possibilities.—The Cristalina District is definitely past its production peak, but is not worked out. Systematic exploration will probably yield some more deposits, and the deeper parts and extensions of some known deposits can continue to produce if warranted by market conditions.

It is difficult to determine whether the Cavalcante-Tocantins District is past its production peak. Because of its large area the possibilities of finding new deposits are good, and it may produce more in the future than it has in the past.

The best future possibilities lie in the north-central Goiaz region. While many known deposits are nearly exhausted, the chances of finding others are excellent because of the immense area involved, the little-explored nature of the country, and the indications of widespread quartz mineralization.

FIG. 2 B. Massive quartz body, Machado Lopes, Tapiratiba, São Paulo, Brazil. Such quartz bodies are being explored in search of nests which carry such commercial quartz.

CRISTALINA DISTRICT.

Location and Topography.—The district is located in southeastern Goiaz (Fig. 1), some 320 km. (200 miles) by road east of Goiânia and 148 km. (92 miles) by road northeast of Ipameri, a station of the Goiaz Railway, 981 km. (610 miles) from São Paulo. Most of the district's commerce passes through Ipameri. Roads into the district are poor and become impassable at times during the rainy season.

The district forms an area of approximately 400 sq. km. (150 sq. mi.) at an elevation of about 1,200 m. (4,000 ft.) on the Goiaz plateau. It is in the

headwater region of the southward flowing Paraná drainage system. It is grass-covered with occasional patches of scrub forest. The mine area is somewhat higher than the surrounding country. Divides are wide with gentle slopes; valleys are shallow and have flat V cross-section. Fig. 3 is a map of Cristalina showing the principal mines.

Geology.—The rocks of the district are cross-bedded quartzites, gray, very fine-grained, medium-bedded, and with thin gray to green shale intercalations. The shale layers increase the impermeability of the enclosing rock so that some pits become wet at depths of as little as 2 meters. Few pits can be sunk deeper than 5 meters without striking water. Cross-bedding in places obscures the true bedding marked by the shale layers. The rock that encloses most of the ore bodies is a soft light gray to white sandstone where cementing

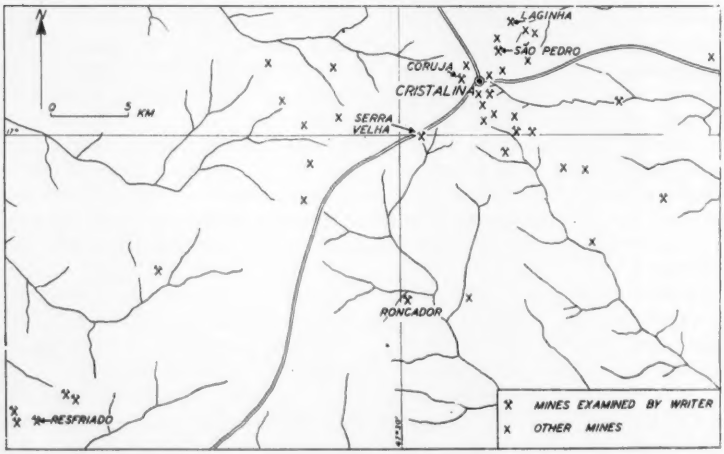


FIG. 3. Map showing location of mines, Cristalina District, Goiaz.

material and coloring matter have been leached from the quartzite. Weathering of the quartzite gives a red to buff colored sandy soil varying in thickness from less than a meter on the ridges to 3 or 4 meters on the lower slopes. In many valley bottoms there is a layer of black peaty mud up to several meters thick.

There is a suggestion that the Cristalina area lies on a large domal structure; the dip of the quartzite on the eastern side of the district is generally southeasterly, and in the mines on the west side of the district it is northwesterly. The dips, however, are very gentle except for a few local rolls. Northeastward trending zones of jointing and faulting are conspicuous structural features at Cristalina. The joints and some of the faults are steeply dipping, but there are also some faults with intermediate dip. In some parts

of these zones the close spacing of fractures has converted the quartzite into a coarse breccia, the fragments of which have a random orientation. Crossing systems of fractures as well as the northeasterly trending ones are well developed in these places.

The ore bodies are associated with folds, faults, and joints. The folds are narrow and abrupt, symmetrical or S-shaped; their axes strike northeasterly. The folds are accompanied by bedding plane faults and occasional small high angle faults, which cut the bedding. In the folded areas steeply dipping northeasterly striking fractures, which look like widely-spaced joints, are abundant and are commonly filled with quartz.

Quartz Deposits.—Commercial ore bodies are of two types: (1) secondary deposits, and (2) bedrock deposits, which may be further divided into (a) flat or gently dipping, and (b) steeply dipping.

Secondary deposits of crystal-bearing gravel are found where erosion has partly or completely destroyed quartz pockets. Most of the gravels are eluvial but locally some alluvial gravels have been formed. Quartz float (cascalho) in the soil is a guide to prospecting. In places, crystal-bearing layers occur under several meters of soil immediately overlying the bedrock. Production from secondary deposits appears to have been greater than that from bedrock deposits. The areal distribution of mine workings in secondary deposits is certainly greater. Depth of workings on secondary deposits varies from less than 1 meter to 4 or 5 meters. At the Resfriado mine, crystal occurs at random on top of bedrock under several meters of soft soil. The deposit is easy to work and lends itself readily to hand-mining by many individual untrained miners.

Bedrock pockets or lenses lie in and along zones of folding and fracturing which strike N. 20–50° E. The valuable crystal occurs in vugs within the larger bodies. Based on structural characteristics, the quartz bodies may be subdivided into flat or gently-dipping deposits and steeply dipping ones.

The gently dipping bodies are more numerous than the steeply dipping ones. In general, the flat or gently dipping deposits are found in areas of the small sharp flexures and tend to follow the bedding. They are of variable size and elongated in the northeast direction; their long dimension may be as much as 25 m. and their thickness up to 1 or 2 meters. However, most of these bodies appear to be less than 10 meters in length. They occur at intervals along the mineralized zone; one may be several meters vertically below another, or it may be offset somewhat to the northeast or southwest in an echelon pattern. At the São Pedro Mine the main pit is about 50 meters in length along a sharp anticlinal fold in the quartzite which has a chord of about 10 meters. The axis strikes northeast and is the locus for flat and gently dipping pockets of milky comb quartz containing some clear material. At the Coruja Mine there are a number of small sharp folds in the nearly horizontal quartzite with lenses of quartz developed between the bedding planes of the quartzite in the minor flexures. The development of openings occupied by the bedding lenses was related to folding.

Quartz bodies in areas where folding is not apparent are associated with steeply dipping fractures that cut the bedding at a high angle. These bodies

vary greatly in size; the Roncador ore body, the largest observed, has a strike length of about 20 m. and a maximum width of 5 meters; it was mined to a depth of 25 m. To the southwest the ore body ends abruptly against a group of eastward striking joints. The quartz is massive but shows sheeting and brecciation. In places the ore body contains inclusions of angular quartzite fragments with random orientation, as indicated by the shale layers. The massive quartzite appears to be slightly arched or domed and is rather highly jointed (four joint systems).

At the Serra Velha Mine the quartz bodies show an echelon arrangement along the strike of the mineralized zone. At the Laginha Mine an irregular tabular body of comb quartz cuts obliquely across the bedding. Mineralization appears to have taken place in the brecciated zone along a fault. In all mineralized areas narrow (2 to 5 cm.) northeastward striking steeply dipping seams of cross-fiber quartz are common.

Minerals present in the ore bodies are quartz and clay. Most of the quartz is milky, coarse-grained, and has comb structure. The large more or less well-formed crystals are arranged in layers with pyramidal terminations pointing inward from the walls. In larger pockets, there may be several layers of the combs, the outer layers being more regular. Some pockets are not completely filled with quartz, and their center may be hollow or filled with sticky light gray to yellow clay. Some of the steeply dipping ore bodies occur in brecciated areas in which the breccia consists of fragments of quartzite and massive quartz veined by yellow clay and quartz.

Most of the quartz contains many cracks and is not clear. A few of the larger crystals have clear pyramidal terminations, and a very few are entirely clear. Small crystals are more likely to be clear than large ones. The size of clear crystals varies from a few grams to 10 kg. or more, but most of the marketable crystals are of small size. Most of the clear crystal is found in hollow or clay-filled vugs intimately intergrown with well-formed but defective crystals.

CAVALCANTE-TOCANTINS DISTRICT.

Location and Topography.—The Cavalcante-Tocantins District is located in east-central Goiaz (Fig. 1) about 350 km. (220 mi.) northeast of Goiânia (at 14 S. lat. and 48 W. long.). At present most of the district's commerce is carried by truck from Anápolis to São José de Tocantins over poor roads that are often impassable during the wet season. The road from São José de Tocantins to São Luiz, the district's only town, is passable to trucks only when the Bagagem River is at very low water. Therefore, transportation within the district and most commerce with the outside world is by pack animal. Veadeiros, a village on the east side of the district, may be reached by truck from Formosa and Cristalina; formerly the district's crystal was exported by this route.

The district is large, comprising about 6,000 sq. km. (2,300 sq. mi.). The region is one of high relief. The Tocantins River and its tributaries have deeply dissected the Goiaz Plateau, whose general level is approximately 1,200 m. Valleys are narrow and steep sided. Only the main stream (the Tocan-

tins) has widened its valley appreciably. In the São Luiz area the level of the Tocantins River is 500 m. below the highest peaks. (Figs. 4B, 4C, and 4D show the type of topography at São Luiz.) Fig. 5 is a map of the area showing the approximate location of the mines examined. It was not possible to visit all of the small mines in the district. The area S.SW. of São Luiz, especially, has numerous deposits which were not examined.

Geology.—The country rock of the district is a series of gray fine-grained quartzites. Two stratigraphic units are recognized. The upper one is a series of massive cross-bedded strata about 300 m. in thickness. This group of beds forms the general plateau level and the ridges which project above it. The lower one is a series of thin-bedded strata with a considerable proportion of shaly beds; it crops out in the centers of anticlines from which the upper quartzites have been eroded. The stratigraphic horizons for the quartz deposits consist of the bottom of the massive series and the top of the thin-bedded series.

In the vicinity of quartz bodies leaching of coloring matter and cementing material has converted the quartzite to a soft, light colored sandstone. Weathering of the quartzite yields a light colored sandy soil, which in most places is very shallow due to the steep slopes. Most of the mines are dry as a result of the steep topography and permeable sandstone.

Structurally the quartzites lie in a succession of large open folds (up to several kilometers across) separated by wide areas in which the bedding is nearly horizontal. The axes of the folds have a northerly trend (N. 30° W. to N. 15° E.); most of them are asymmetric with dips of 20° to 40° on the gentler (westerly) limb. Near the axes dips become steeper and in places vertical. The anticlines have been breeched by erosion and one or both limbs form ridges of massive quartzite. The favorable stratigraphic horizon for quartz deposits lies at the bottom of this massive quartzite series, and consequently many of the quartz deposits crop out on steep slopes and are reflected as topographic highs (Fig. 4D). In the eastern part of the district, where the topography is less rugged, there are a number of peaks that suggest block faulting of the basin range type.

In addition to the small scale faulting related to the folding, faulting oblique to the trend of the fold axes is indicated by the displacement of anticlinal limbs. Some of these faults show horizontal movement amounting to 300 meters. The massive quartzite is jointed, especially where there is some cross-folding or warping. In the thin-bedded series drag folds and associated breaks have been formed (Fig. 7B).

Localization of quartz bodies appears related to combinations of several of the following features: (1) Folding—with few exceptions deposits occur in folded areas where dips are moderate to steep. (2) Stratigraphy—most of the deposits occur near or along the contact between the massive and thin-bedded quartzite series. (3) Faults—most deposits occur in minor faults of one kind or another. (4) Joints—deposits in massive quartzite, especially, follow jointing. (5) Drag folds and associated breaks—many deposits in the thin-bedded quartzite series lie within small scale contortions in the bedding.

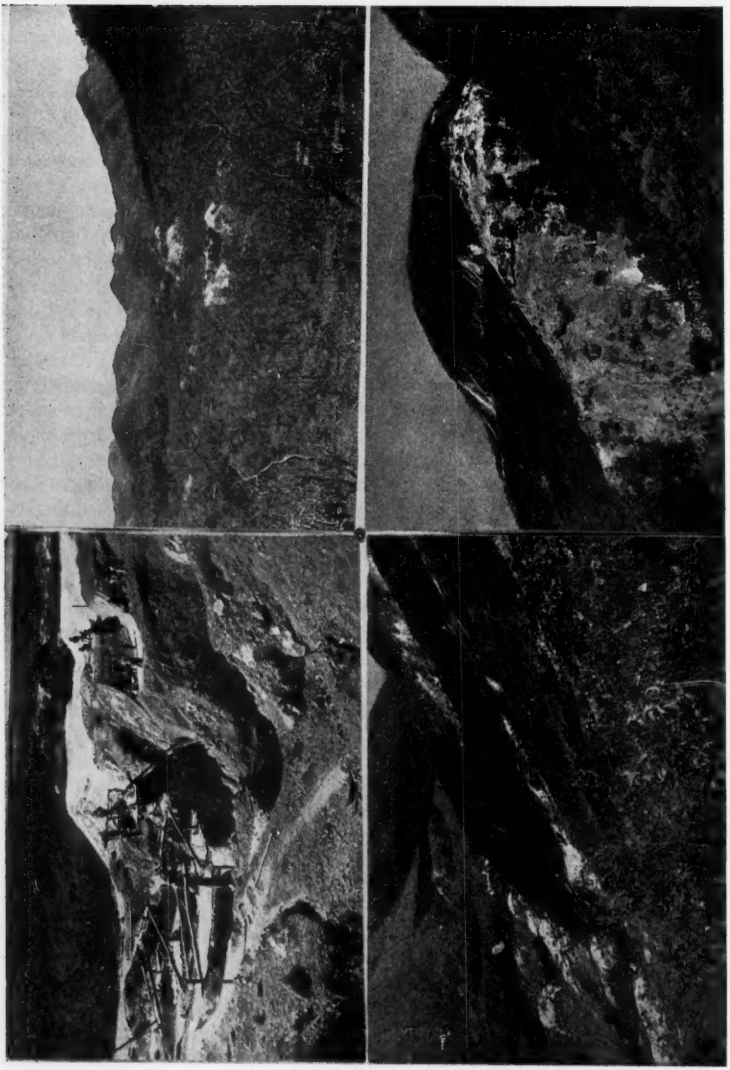


FIG. 4.

Quartz Deposits.—Both secondary and bedrock deposits have yielded commercial crystal; most mines or groups are a combination of both types.

Crystal-bearing eluvial and alluvial gravels occur where quartz bodies have been destroyed or modified by erosion. In a few places, for example Garimpinho, only the secondary deposits were of commercial grade.

Bedrock quartz deposits occur as lenticular bodies of variable size, shape and attitude in the quartzite. The ore bodies consist of quartz with minor amounts of clay, and iron and manganese oxides. The quartz is milky and

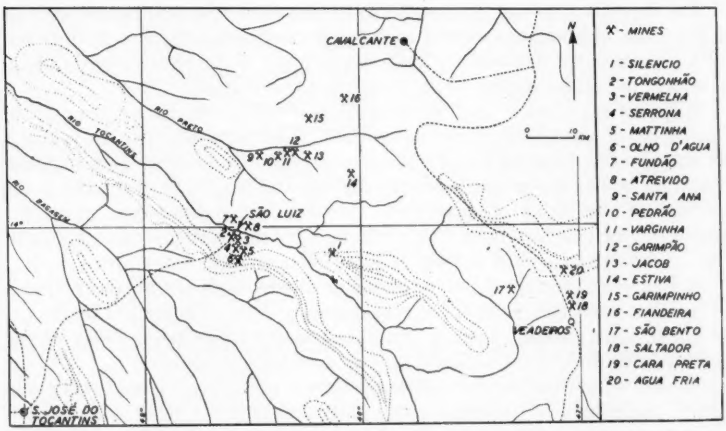


FIG. 5. Map showing location of mines, Cavalcante-Tocantins District, Goiaz.

coarse-grained. In the large bodies in major fault zones it is massive, whereas in the smaller ore bodies it generally has comb structure and is usually arranged in layers. Open cavities are common only in deposits that occur in gently dipping massive quartzite. Quartz crystal of commercial quality is present in very minor proportions. The crystal occurring in large quartz bodies, especially those in major fault zones in thin-bedded quartzites, seems to be of inferior quality to that from smaller ore bodies, especially those in massive quartzite.

FIG. 4 A. Marçal Pit at Pium, Northcentral Goiaz District. Waste is hoisted by windlass and carried to dumps. The Piaus workings are visible in the right background on the other side of the Pium River Valley.

FIG. 4 B. Tongonhão Mine, along the Tocantins River near São Luiz, Cavalcante-Tocantins District, Goiaz. This area is one of high relief.

FIG. 4 C. Part of the Silencio Mine Group, Cavalcante-Tocantins District, Goiaz. Quartz bodies occur in steeply dipping beds of massive quartzite.

FIG. 4 D. Vermelha Mine, São Luiz area, Cavalcante-Tocantins District, Goiaz. A large quartz body occurs in a fault zone in the thin-bedded quartzites, and forms a bench on the mountainside. Some mines of the Serrona Group are visible on the side of the mountain in the background.

STATE COLLEGE OF AGRICULTURE AND APPLIED SCIENCE
LIBRARY
JAN 9 1947
MANHATTAN, KANSAS

On the basis of enclosing rocks and structural features the deposits may be classified as follows:

A. Deposits in massive quartzites
   1) In gently dipping beds
   2) In steeply dipping beds
B. Deposits in thin-bedded quartzites
   1) Associated with major fault zones
   2) Associated with drag folding and minor faults

The deposits listed as A-1 are the most abundant type and comprise those on the limbs of anticlines as well as a few located some distance from major folds. Some of the deposits are in the bottom part of the thick bedded quartzite series; the others appear to be stratigraphically higher.

With few exceptions (such as the northeast end of the Estiva group), the localization of this group of deposits seems to be related chiefly to jointing, the attitude and location of which was controlled by bedding and warping. The larger bodies are generally steeply dipping and tend to be elongated in the direction of the strike of quartzites. Smaller ore bodies occur along the bedding. Open cavities lined with crystals, some of which are clear, are common. Commercial crystal is frequently of good quality.

At Fiandeira the deposits occur on the northwest limb of a northeast trending anticline; quartzite beds in the area dip about 10°. The quartz bodies occur either along steeply dipping joints or bedding (Fig. 6A). Part of the Garimpão deposits have a similar occurence to those at Fiandeira.

At Estiva the thick bedded quartzites have a northeast regional strike and a gentle undulate dip. There are two groups of deposits about 2 km. apart. The southwestern group is associated with a northwest trending monoclinal cross fold with bedding dips of as much as 40° southwesterly. Jointing is well-developed in the area, steeply dipping sets striking parallel or perpendicular to the strike of the quartzites being the most conspicuous. The irregular quartz body is bounded by planes which probably represent joint directions. (Fig. 7A shows part of this ore body.) The northeastern group of deposits consists of a stockwork of closely spaced steeply dipping massive quartz bodies. One nest of large well-formed crystals surrounded by sheeted massive quartz was observed. The location of this group of deposits seems to be related to a fairly large fault which strikes parallel to bedding and dips steeply.

Some of the deposits of the Serrona group occur in the basal part of the thick-bedded quartzite series along the west limb of the N–S trending São Luiz Anticline (Fig. 4D).

The deposits listed as A, 2, are represented by the Silêncio group (Fig. 4C), which is the only example of this type seen; it is on the steep limb of an asymmetric anticline. Small quartz bodies occur along the bedding and along joints and small faults.

The deposits listed as B, 1, are relatively large and appear to be stockworks in which individual quartz lenses are large and closely spaced. They occur not far below the contact with the overlying thick-bedded quartzite series. They appear to have been formed along major fault zones that strike north to

northeasterly, parallel to the fold axes, and dip westerly, generally more steeply than the bedding. The quartz is massive, comb structure not being very well developed, and large vugs are rare. Some very large crystals are found. The commercial crystal is not of particularly good quality. Examples of this group are Vermelha (Fig. 4D), Tongonhão (Fig. 4B), Santa Ana, Atrevida, and part of Fundão and Garimpão.

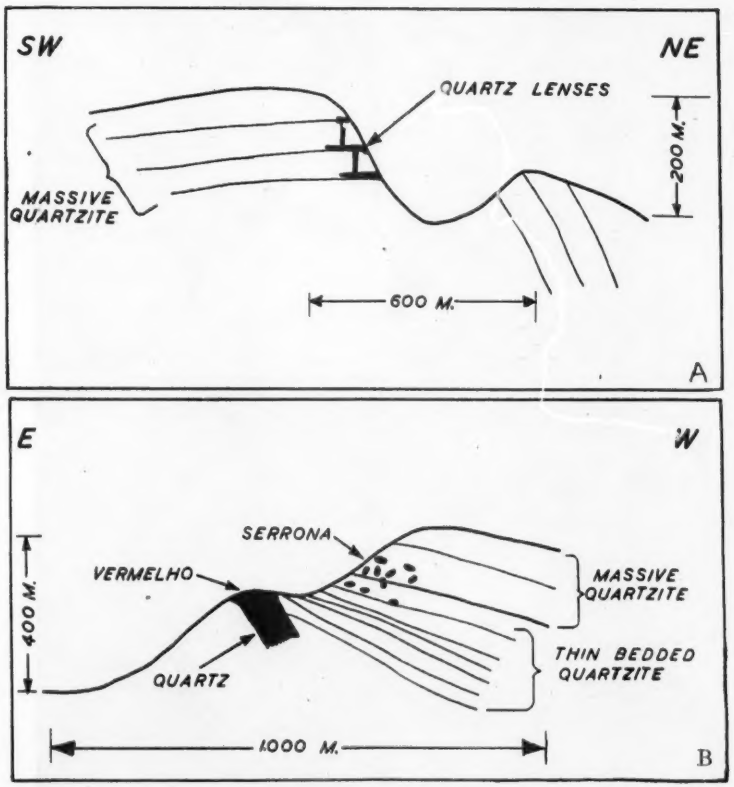


FIG. 6. Cross-sections at Cavalcante-Tocantins District, Goiaz. (A) Fiandeira mine; (B) Vermelha and Serrona mines.

The deposits listed as B, 2, are ore bodies found on major anticlines. They occur in the top part of the thin-bedded quartzite series in fractures associated with contorted beds. Favorable places for their localization are: (1) on limbs of folds just below the contact with the thick-bedded quartzite series (Fig. 6B), and (2) in the axial region of the folds (as other members of the Serrona group, see Fig. 7B).

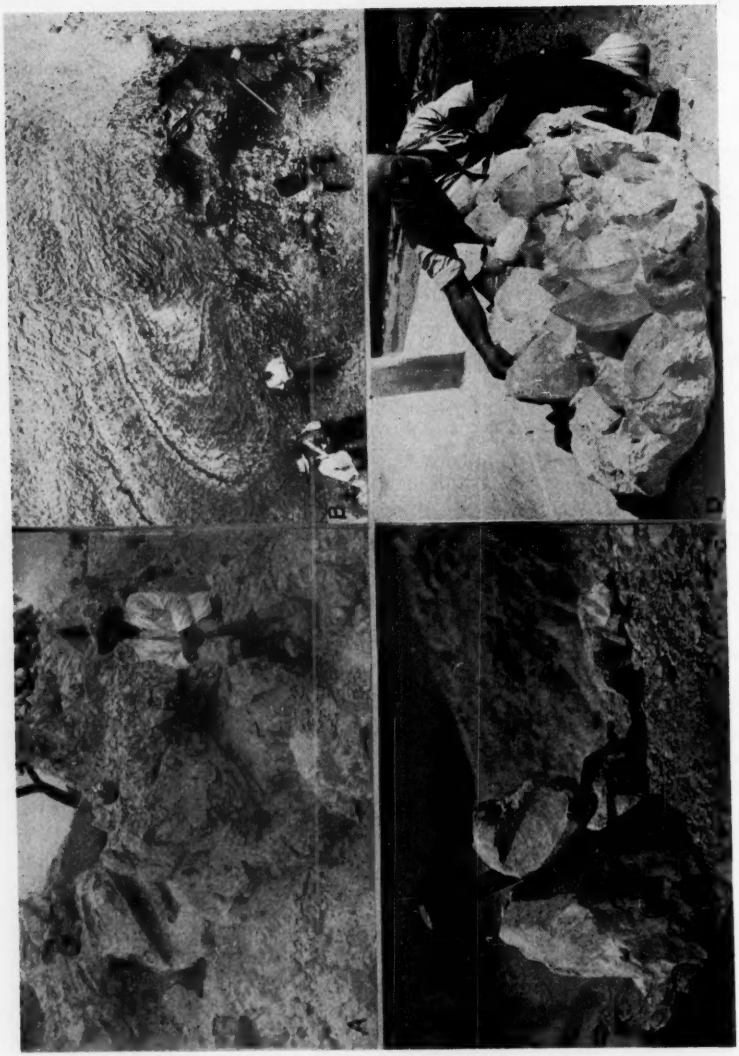


FIG. 7.

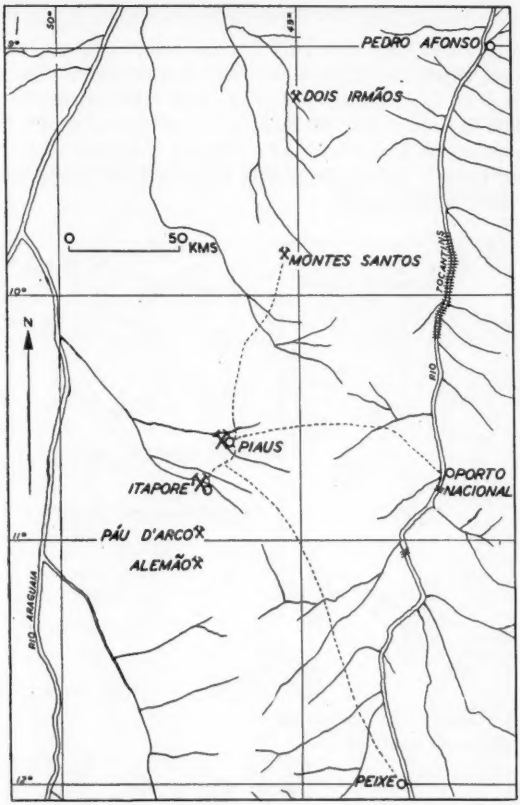


FIG. 8. Map showing location of mines, Northcentral Goiaz District.

FIG. 7 A. Quartz body at the Estiva Mine, Cavalcante-Tocantins District, Goiaz. The quartz shows layered and comb structure with pyramidal terminations. The cavity over the man's head was caused by erosion of a sandstone segment of the wall; however, vugs are common within the quartz.

FIG. 7 B. Contorted beds of thin-bedded quartzite series, Serrona Mines, São Luiz area, Cavalcante-Tocantins District, Goiaz. A quartz body occurs at the right center.

FIG. 7 C. Mould and caste caused by intergrowing quartz crystals, Otasil-Leobas Pit, Piaus mine area, Northcentral Goiaz District. This chunk of quartz was found in place in an outcrop; the two pieces fit together.

FIG. 7 D. Nest of crystals from Fedoca Pit, Piaus mine area, Northcentral Goiaz District. Interstices were filled with sticky gray clay.

NORTHCENTRAL GOIAZ DISTRICT.

Location and Topography.—This district, comprising the crystal mining camps of Pium, Piaus, and Itaporé, is located in northcentral Goiaz about 750 km. (450 mi.) north of Goiânia (Fig. 1) and 700 km. north of Anápolis. Transportation is costly and difficult; most of the district's commerce is through Anápolis, the Goiaz railhead. Freight is hauled in and crystal out via truck and plane. Piaus, the largest town and the commercial center of the district, has a small airport.

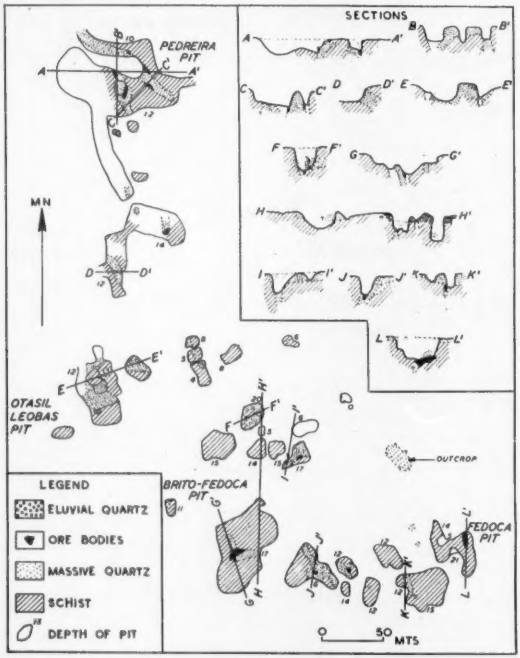


FIG. 9. Piaus mine area, Northcentral Goiaz District.

A little commerce comes in from Belém by transport on the Tocantins River to Porto Nacional. There are poor automobile roads between Piaus and Peixe and between Piaus and Porto Nacional. Truck transportation is possible only during the dry season. Because of lack of bridges, trucks can get through from Peixe only when the rivers are very low (July to September). Within the district there are automobile roads from Piaus to Itaporé and Montes Santos (Fig. 8). (The district is served by several air lines and air service is more dependable than overland transport.) The district is very large, comprising some 35,000 sq. km. (13,500 sq. mi.) in the area be-

tween the Tocantins and Araguaia rivers. It has low relief with wide flat interstream areas and wide shallow, flat-bottomed valleys. Its elevation is 200 to 300 meters and most of it is covered with a thin scrub forest.

Fig. 8 is a map showing the approximate location of the principal mine groups. It was not possible to visit all of the mines in the region.

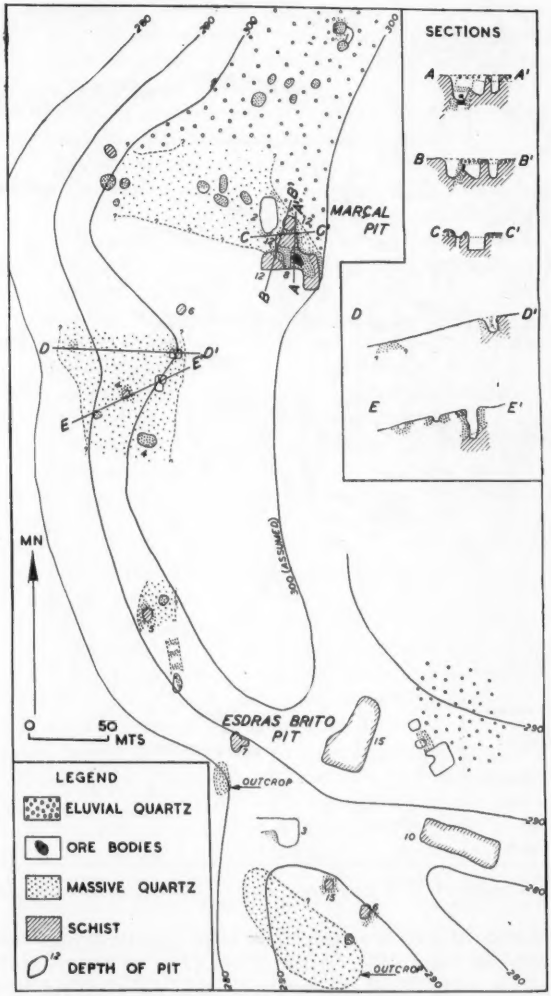


FIG. 10. Pium area, Northcentral Goiaz District.

Geology.—An extensive erosion level has been developed in the region and the present valleys are cut into this surface. The erosion surface is capped by a veneer of gravel up to several meters thick, which is cemented by limonite in many places. In the valleys there is a clay soil veneer in most places.

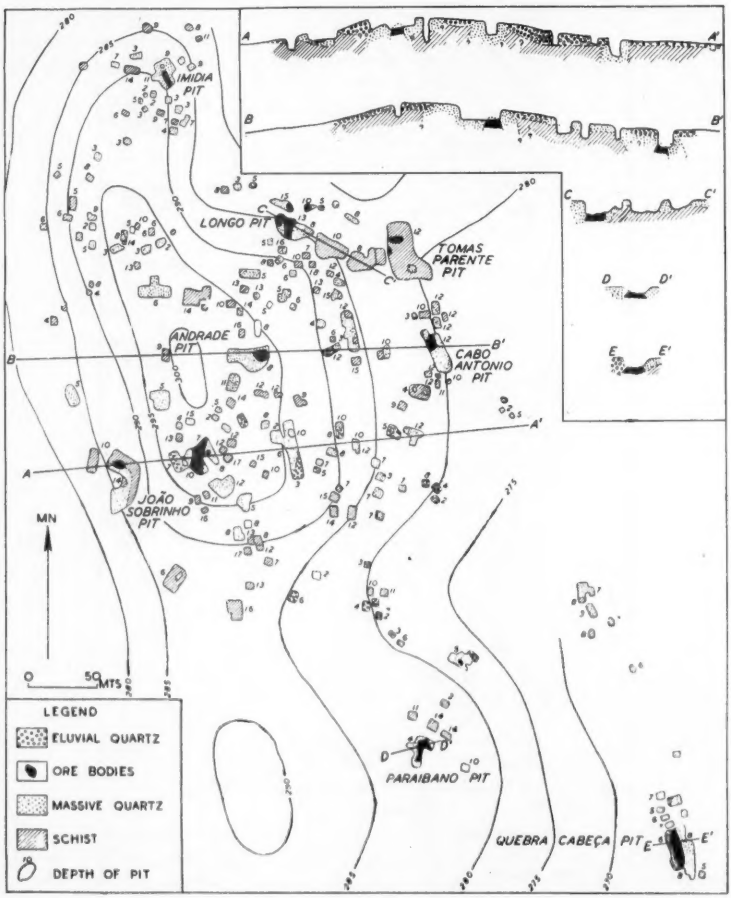


FIG. 11. Manchão Felipé mine area, Itaporé, Northcentral Goiaz District.

Many mineralized areas are topographic highs because of their resistance to erosion. Both the Piaus (Fig. 9) and Pium (Fig. 10) areas are remnants of the older level. The Piaus area is a spur from the south rim of the Pium River Valley. The Pium area (6 km. N 20° W of Piaus) is a spur from the

north rim of the same valley. Manchão Felipé (Fig. 11), in the Itaporé area, is a ridge projecting above the general level.

The bedrock of the district is mica schist, deeply weathered and altered to a reddish-brown color. It is contorted, faulted and jointed. The mechanics of formation and localization of fractures in the schist is not understood and the relation of quartz bodies to schist structures is obscure. It appears that in the vicinity of quartz bodies the attitude of the schistosity is quite variable from one fracture-bounded block to another, that development of white kaolin is more pronounced and that the schist is softer and wetter than at some distance from the quartz.

Quartz Deposits.—Commercial crystal occurs in gravel deposits and in lenses and pockets associated with quartz bodies in schist.

Secondary deposits consist of eluvial and unimportant alluvial gravels formed through the weathering and erosion of crystal-bearing lenses in and around the quartz bodies. They are areally more extensive than bedrock deposits. In general, secondary deposits were more productive than bedrock deposits; they produced at least twice as much crystal as the latter. Depth of workings on secondary deposits varies from 1 to 5 meters; in some places they reached the water table. In places where quartz bodies cropped out on the extensively developed erosion surface, commercial crystal occurs in the veneer of limonite-cemented gravel.

Bedrock deposits of commercial crystal, intimately associated with non-commercial quartz and clay, occur in pockets and veins in and around quartz bodies enclosed in schist. Most of the production comes from larger stones; small faceted stones are rare.

The quartz bodies vary from veins less than one meter wide to chimneys 20 or 30 meters across which have been worked to depths of 20 meters. The arrangement of the bodies suggests a stockwork, the distance between the quartz bodies being rather great. The larger bodies tend to be chimney-like and steeply dipping; the veins are irregular in dip and strike. At Piaus the larger bodies are bounded by a series of diversely oriented planes, which may correspond to joint directions in the schist. Ingerson observed and plotted several hundred joints and contact surfaces of the quartz bodies in the Pedreira, Otasil-Leobas, and Brito-Fedoca pits (Fig. 9). This work showed lack of a common fracture pattern in and around the bodies.

The quartz bodies consist of coarse massive and comb quartz with some clay and limonite. An occasional pyrite crystal and limonite pseudomorphs after pyrite are found in the quartz. The color of the quartz varies from milky white through brownish gray. Some is fleshy pink in color (similar to certain perthitic microcline as described by Johnston). The structure in most places is massive, but there are places where a closely spaced (5 to 10 mm.) sheeting has been developed. The sheeting together with less well developed cross fracturing gives the quartz a blocky structure remarkable because of its resemblance to feldspar, particularly where the quartz is flesh-colored. Much of the quartz shows impressions caused by intergrowth of other crystals (Fig. 7C).

In many places a fine-grained variably colored rock consisting of rounded quartz crystals (about 3 mm. long) with more or less clay and limonite is associated with the quartz. This rock contains a higher proportion of clay than the rest of the quartz. Much of the limonite occurs as pseudomorphs after small (less than 1 mm.) pyrite crystals. The color of the fine-grained rock in most exposures is greenish-brown to gray; but it may be dark rust colored, various shades of yellowish brown, or white. Its color is probably determined by the amount and state of oxidation of the pyrite originally contained. This rock tends to form an envelope around the quartz bodies, although it is not present everywhere along their walls. Where present, its thickness varies from a few centimeters to more than a meter; it tends to be thicker on the footwall side of the quartz bodies. Veins of this material are occasionally found a considerable distance away from large quartz bodies. In places, irregular bodies of this rock contain separated lenses of quartz and occasional crystals of commercial quality. Many pockets containing commercial crystal occur immediately over or alongside of this greenish fine-grained material, and a few pockets occur in it.

The four major producing pits at Piaus have been:

1. Brito-Fedoca	20	metric	tons	(appr.)	of	commercial	crystal
2. Pedreira	8	"	"	"	"	"	"
3. Otasil-Leobas	1	"	"	"	"	"	"
4. Fedoca	1	"	"	"	"	"	"

With the exception of the Fedoca Pit, this crystal production was obtained from the peripheral zone and adjacent to large quartz bodies, that is, ones which yielded 100 cubic meters or more of non-commercial quartz per meter of depth. Very few of the smaller quartz bodies have appreciable amounts of commercial crystal associated with them. The commercial crystal came from without rather than from within the coarse quartz. At the Brito Fedoca Pit commercial crystal associated with greenish fine-grained material (described above) was being mined from the hanging wall side of a large quartz rib which dipped about 60° northerly. There is some suggestion that a swell on the top of the rib was the most favorable place for deposition. At the Pedreira and Otasil-Leobas pits most of the commercial crystal is reported to have come from pockets along the steep walls of the chimneys. There are no data to indicate whether or not crystal was associated with selvages or apophyses of greenish fine-grained material, but this material is present in some places around the chimneys.

In the Fedoca Pit, at the southeast side of the mapped area of Fig. 9, commercial crystal in appreciable amounts was being mined from a quartz-clay body associated with the greenish fine-grained material. This ore body showed no close association with any large quartz body.

The commercial ore bodies at Piaus are generally of small size, less than 5 m. in strike length. The largest seen (Brito-Fedoca) had a strike length of about 10 m. and had been mined down the dip for 20 m. Only a small proportion of the crystal from any ore body is of commercial quality. The commercial crystal is embedded in sticky light gray clay. Quartz dealers

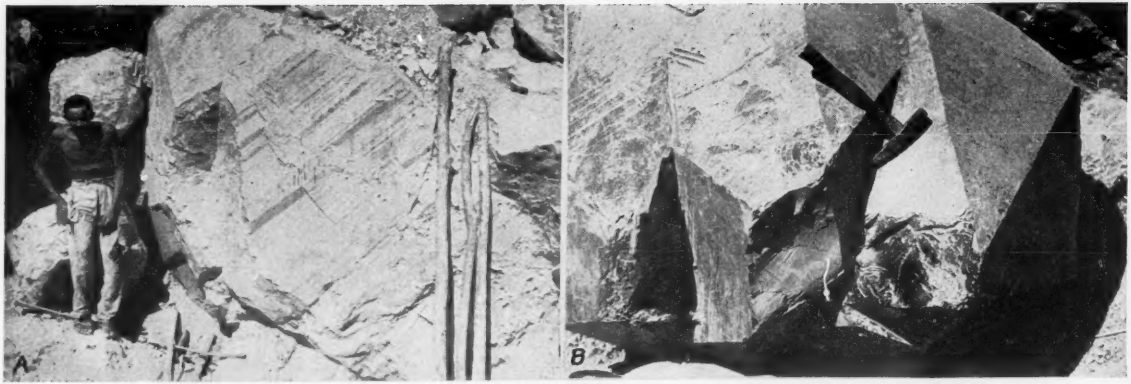


FIG. 12 A. Large quartz crystal, Longo Pit, Manchão Felipé, Itaporé area, Northcentral Goiaz District. This is one of the largest in a nest of about 30 big crystals.

FIG. 12 B. Large quartz crystal with clear portion at point from nest of big crystals in the Cabo Antonio Pit, Manchão Felipé, Itaporé area, Northcentral Goiaz District. This crystal was broken up by blasting and, in spite of waste, gave 120 kg. of commercial quality crystal.

FIG. 13 A. Edge of the nest of big crystals in Longo Pit, Manchão Felipé, Itaporé area, Northcentral Goiaz District. The breccia at left is chiefly eluvial.

FIG. 13 B. Top of the nest of big crystals in the Cabo Antonio Pit, Manchão Felipé, Itaporé area, Northcentral Goiaz District. The nest is overlain by sheeted massive quartz and eluvial material.

estimate that at Piaus about 25 percent of the commercial (saleable) crystal is actually of radio quality.

Manchão Felipé, 2 km. southwest of the town of Itaporé, was the principal producer during 1945 in the Itaporé area. Fig. 11 is a map of part of the Manchão Felipé hill. Most of the ridge surface is covered by a veneer of eluvial and alluvial quartz which in places attains a thickness of 10 meters. In many places it is difficult to distinguish between eluvial material and quartz veins in place.

The outstanding geological feature of Manchão Felipé is the presence of nests of enormous well-formed quartz crystals in some of the massive quartz bodies. Crystals up to 6 m. long with the prism face of 1.5 m. wide were seen. Most of the area's production comes from these nests. Fig. 2B shows a typical massive quartz body. Figs. 12 AB and 13 AB show some of the big crystals. The crystal nests in the Cabo Antonio, João Sobrinho, and Longo pits (Fig. 11) are especially noteworthy. The Cabo Antonio nest contained a higher-than-average proportion of commercial quality crystal, usually found in the pyramidal terminations of the big crystals (Fig. 12B). The nest in the João Sobrinho pit was exposed in an area 25 m. by 10 m. over a vertical interval of at least 3 m. The crystals in the Longo nest are exceptional from the standpoint of sheer size (Figs. 12A and 13A) but they contained very little commercial quality crystal.

The large crystals of the nests are more or less cracked and randomly oriented. They seem to occur individually with interstitial spaces filled with broken quartz and yellowish to gray clay. In some places the interstices contain a reddish brown material appearing superficially like crushed schist. In all cases the nests are at least partially surrounded by a zone of sheeting in the massive quartz (Figs. 13BCD). The sheeting strikes northerly parallel to the long axes of the quartz bodies and is steeply dipping. Johnston [3] attributes the sheeting of the massive quartz and the movement of the big crystals to post-quartz faulting. The sheeted zones are less resistant to erosion than the rest of the quartz, and cause trench-like depressions, filled with eluvial material. The sheeting could be used as a guide for prospecting the large massive quartz bodies for nests of crystals.

The Baixa da Égua workings, 2 km. WSW of Itaporé, are noteworthy for the occurence of commercial crystal in large bodies of greenish fine-grained rock, which form irregular dike-like and sill-like bodies in the schist. They contain irregularly distributed small lenses of massive quartz with which good crystal (small faceted stones) is intimately associated. These ore bodies do not show up as topographic highs.

[3] Johnston, W. D., Jr.: oral communication.

FIG. 13 C. Contact between sheeted massive quartz and eluvial quartz in the NW end of the Longo Pit, Manchão Felipé, Itaporé area, Northcentral Goiaz District.

FIG. 13 D. Sheeted massive quartz in the SW side of the Longo Pit, Manchão Felipé, Itaporé area, Northcentral Goiaz District. This view is just to the left of that in Fig. 13 C. The edge of the nest of big crystals is visible at the lower left.

CONCLUSIONS REGARDING FORMATION OF DEPOSITS.

The crystal deposits in Goiaz occur in essentially monomineralic quartz veins. The structures in the veins, such as vugs, comb quartz, intergrowing crystals, and crystals pointing away from walls, indicate that during deposition open spaces existed and the quartz was deposited in them as a filling. Suggestions of replacement are rare, and megascopic evidences of hydrothermal alteration of wall rocks are confined to leaching of the cementing material in the quartzite and bleaching of quartzite and schist.

In the Cavalcante-Tocantins and Cristalina areas most of the minor fractures and folds in which the quartz occurs are obviously related to major structures that are well displayed. In these districts structural openings may have been expanded by a solvent action of solutions, and later solutions, or the same ones with changing conditions, deposited the quartz in the spaces thus formed. This is suggested by the configuration of the curving walls of many of the quartz bodies.

In the Northcentral Goiaz District major structures in the schist could not be distinguished because of the deep weathering and lack of stratigraphic markers; the deposits occur along fractured zones in the schist. Many of the quartz bodies are bounded by plane surfaces making it appear that solution was not important in the formation or enlargement of the openings which were filled with quartz.

The large size of some of the quartz bodies might be attributed to the formation of openings and their filling proceeding at the same time and approximately at the same rate. Brecciation and sheeting of the quartz were probably caused by the continuation (or recurrence) of the same kind of stresses which originally caused the openings.

Commercial crystals, as well as the closely associated milky euhedral crystals, were deposited late in the period of quartz mineralization, as indicated by their occurrence in vugs and veins cutting the massive quartz which forms the quartz bodies. Crystal deposition was followed by clay deposition, which may have been primary. Ingerson collected clay samples and will have additional information on this point when their mineralogical composition has been determined. Iron oxides (except specularite which is an uncommon inclusion) and manganese oxides were formed much later through secondary processes. They occur staining clay, coating and veining quartz, and occasionally veining clay.

The greenish fine-grained rock, common in the Northcentral Goiaz District, is thought to be earlier than most of the quartz. It occurs as a border phase of some of the quartz bodies, and was not observed cutting massive quartz. Many pockets containing commercial crystal occur immediately over or alongside the greenish fine-grained rock and a few crystal-bearing pockets occur within it. The rock appears to have been more permeable than the massive quartz. The quantity of iron oxide present indicates that it carried more pyrite than the massive quartz; it now contains a rather high proportion of clay.

If the quartz veins with their crystal deposits are classified according to Lindgren's classification, they would fall most reasonably into the lower tem-

perature mesothermal range. This estimate is based on the mineral composition (quartz), the structure (filled openings), the depth of formation (shallow enough for large openings and brecciation without crushing), the absence of high temperature minerals and metamorphic effects and coarse texture. The giant crystals and general coarse textures indicate an unhurried and long continuing precipitation from solutions under constant conditions which would not be expected if the depth of formation had been extremely shallow. The occasional occurrence of specularite as inclusions in some of the crystal of very large quartz bodies (ex. Vermelha Mine in the Cavalcante-Tocantins District) might indicate that some of the deposits formed at higher temperature, but not necessarily since crystals of hematite have been formed in the laboratory below 300°C. No intrusives to which the origin of solutions could be related were seen anywhere in the region.

FOREIGN ECONOMIC ADMINISTRATION,
WASHINGTON, D. C., AND
UNIVERSITY OF ARIZONA,
TUCSON, ARIZ.,
May 6, 1946.

BIBLIOGRAPHY.

1. Johnston, W. D., Jr.: Cristal de Rocha em Cristalina, Estado de Goiaz. Avulso N. 57, Ministério da Agricultura, Departamento Nacional da Producão Mineral, Divisão de Fomento da Producão Mineral. Rio de Janeiro, Brasil, 1944.
2. Oliveira, A. I. and Leonardos, O. H.: Geologia do Brasil, Série Didatica N. 2, Servico de Informacão Agrícola, Ministério da Agricultura. Rio de Janeiro, Brasil, 1943.
3. Shearer, H. K., and de Souza, H. C. A.: Araguaia Recursos Minerais. Boletim N. 61, Ministério da Agricultura, Departamento Nacional da Producão Mineral, Divisão de Fomento da Producão Mineral. Rio de Janeiro, Brasil, 1944.
4. Johnston, W. D., Jr., and Butler, Robert D.: Quartz Crystal in Brazil. Bull. Geol. Soc. Am., in course of publication.

STATE COLLEGE OF AGRICULTURE AND APPLIED SCIENCE
LIBRARY
JAN 9 1947
MANHATTAN, KANSAS

MOVEMENT OF MINERALIZING SOLUTIONS IN THE PICHER FIELD, OKLAHOMA–KANSAS.

RICHARD E. STOIBER.

ABSTRACT.

Evidence regarding the horizontal component of motion of the solutions which deposited the ore minerals in the Picher Field of northeastern Oklahoma and southeastern Kansas has been obtained from 159 localities in the mines in the area. Position of minerals and a symmetry of growth were interpreted according to the criteria of Newhouse. It appears that the direction of the horizontal component of solution flow can be determined within plus or minus 10 degrees. The difficulties involved in the interpretation of the vertical component of motion are discussed. These chiefly relate to the importance of gravity settling during precipitation of the minerals from solution. Conclusions from this study, therefore, are largely confined to those concerning the horizontal component of solution motion. The general similarity of direction of flow indicated by several different ore minerals suggests that the solutions had a similar horizontal component of direction throughout the period of ore deposition. The flow directions found are those which would be shown by solutions which spread laterally from the Miami shear trough, the major structure in the field. To the east of the trough, solution movement directions recorded are mostly southeasterly or southwesterly. To the west of the trough, the directions recorded are mostly northeasterly and northwesterly. It is postulated that the north-south tension fractures found in the region of the trough were the paths followed by solutions as they left the trough, and that the solutions spread from these channelways into a northeast-northwest system of fractures. In these fractures the solutions flowed southeasterly and southwesterly in the area east of the trough and northeasterly and northwesterly in the area west of the trough to reach the minor folds, domes, basins and fracture zones which have been shown by other investigators to be loci of ore deposition in this field.

INTRODUCTION.

METHODS of interpreting the direction of solution flow during mineral formation were applied to the lead-zinc ores of the Picher field, the major zinc-producing district of the Tri-State area. The data are the results of field and laboratory study of the position and asymmetric form of the crystals growing in cavities and caves in these deposits. The horizontal component of the direction of movement of the mineralizing solutions in the district is postulated from these data and considered in relation to structural studies of the field made by other investigators. Difficulties involved in the interpretation of the vertical component of motion have limited most of the discussion to a consideration of the horizontal component of the direction of solution flow.

ACKNOWLEDGMENTS.

The author acknowledges with thanks a grant from the Penrose Fund of the Geological Society of America which defrayed field expenses and release of manuscript for publication. Discussion with Professor W. H. Newhouse was most helpful and aided both field and laboratory studies. The kindness of Mr. George M. Fowler, whose introductions and familiarity with the district made it possible to see much of the field, is gratefully acknowledged. The engineering staff of the Eagle Picher Mining and Smelting Company made many of the mine visits possible, and the kindness of Mr. Evans Just and Mr. Joe Arundale of the Lead Zinc Ore Producers Association of Picher greatly facilitated the field work.

COLLECTION OF DATA AND CRITERIA USED.

During a six-week period in the summer of 1941 crystals were examined in cavities containing lead-zinc sulphides in an area of about 40 square miles in the mines around Picher in northeastern Oklahoma and adjacent southeastern Kansas. Study of crystal-lined cavities was most often possible at the working faces and in pillars in newer parts of the mines. Little data could be gathered in mines in which high water had covered the exposed faces with mud.

Criteria which may be used to determine the direction of movement of mineral-depositing solutions have been discussed by Newhouse.[1] The criteria fall into two groups, the position of crystals in cavities and the asymmetrical shape of single crystals. With respect to the position of crystals in cavities it is pointed out that crystals grow larger and more plentifully on the stoss side of irregularities in the walls of the cavity. It is also noted that crystal overgrowths are larger and more plentiful on the stoss or "upstream" side of other crystals which act as irregularities in the walls of the cavity. Studies of asymmetrical shape of single crystals showed that the greatest departure from the normal shape, which results from the unequal addition of material to the crystal during growth, is to be found on the stoss side of a crystal. It is pointed out that the lineages, the branching growths in a crystal, are longest toward the "upstream" direction. Growth banding is also asymmetric in crystals, the bands being wider toward the side from which the crystal is nourished, the "upstream" direction. These criteria were used in these studies and their validity is substantiated by the consistency of interpretation repeatedly obtained in a single locality when two or more criteria were applied. As indicated by Newhouse more than one crystal must be examined and the accuracy with which the direction can be interpreted varies with the criterion used. The applications of these criteria in this study are discussed in the following paragraphs.

Asymmetrical Crystal Growth.—The shape of galena crystals growing on an approximately horizontal surface departed from that of a cube (Fig. 1). The longest horizontal dimension of each of a number of crystals in the same

[1] Newhouse, W. H.: The direction of flow of mineralizing solutions, ECON. GEOL. 36: 612–629 (1941).

cavity was observed. The average of these directions was taken to indicate the line of flow and the wider ends of the almost rectangular blocks was interpreted as indicating the direction from which the solution came. In groups of abutting crystals the long dimension of the group rather than the elongation of individual crystals in the group appeared to yield more accurate evidence of direction when data were compared with that derived from other evidence in the same location. Oriented galena specimens collected in the field were later sectioned, polished and etched and the growth zones studied. Wider growth zones on the stoss side confirmed field evidence. The center of radi-

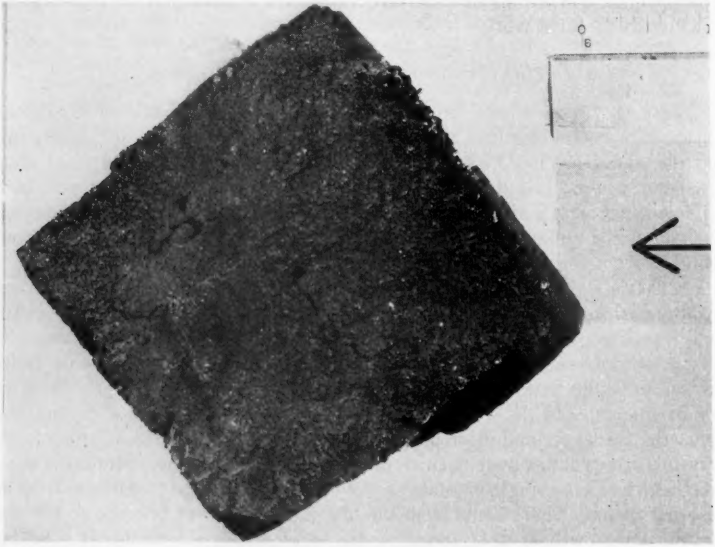


FIG. 1. Single crystal of galena from roof of a cavity in the Eagle Picher Gordon Mine. Viewed from below. Arrow indicates postulated horizontal component of direction of solution movement; also verified by observation of other crystals in the same cavity. Growth distortion (asymmetry) in "upstream" direction.

ating lineages was also determined on a series of cleavage planes in single galena crystals. The direction of solution movement inferred from the evidences of lineage and shape checked closely in the same crystal (Figs. 1, 2). Negative cavities in galena, more common on the lea side,[2] were noted. They checked other determinations in several instances. Evidence from negative cavities was seldom easy to interpret within close tolerances but served to indicate the general direction. About one-fifth of the determinations recorded as a result of field and laboratory study were inferred from observations of

[2] Newhouse, W. H.: op. cit., pp. 622–623.

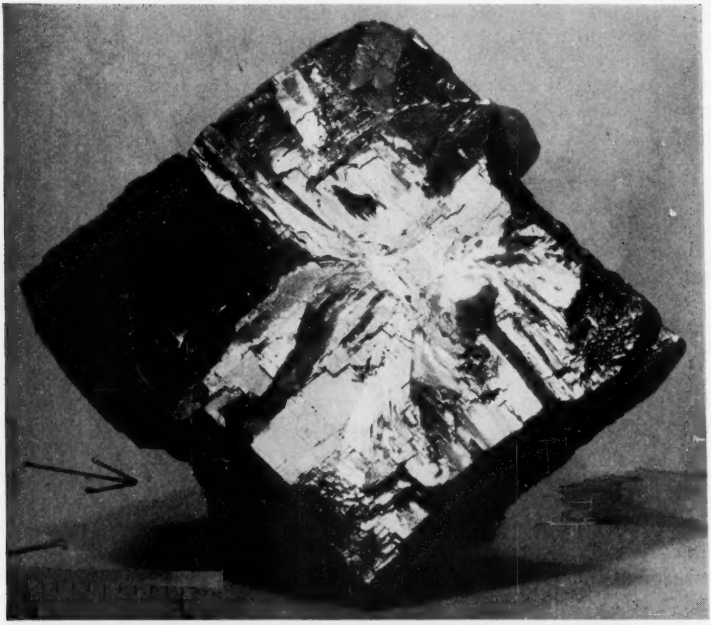


FIG. 2. Cleavage section of same galena crystal as FIG. 1. Viewed from above. Center of lineage structure is to the right of center, "downstream." The postulated direction of the horizontal component of solution flow is indicated by arrow.

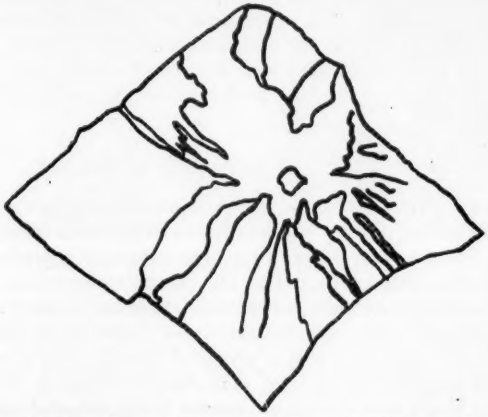


FIG. 3. Outline drawing of the lineage pattern in Fig. 2 to show more clearly than the photograph the relation of the small central nucleus (square, near center of the crystal) to the branching lineages. Scale and orientation same as Fig. 2.

asymmetrical growth of the various types described. Further laboratory work on oriented specimens collected would have added more data of this sort. Galena was the one mineral occurring in the ores in this district which most often and most obviously showed asymmetrical growth. The asymmetry of chalcopyrite crystals or of calcite crystals was so small as to be difficult to note in the field and was not used in this study.

Position of Crystals on Cavity Walls and Roof.

Sphalerite, galena, dolomite, calcite and less often marcasite and chalcopyrite crystals were observed to have grown more plentifully on one side of undulations or irregularities of cavity floor, wall, or roof. This was interpreted as the stoss or "upstream" side. About forty per cent of the determinations of solution flow direction were of this kind. Protuberances of jasperoid hanging in vugs were coated with crystals on one side and had very few or no crystals growing on the other side (Fig. 4, *A, B*). Very small undulations or rolls in the wall, some as small as a quarter of an inch in amplitude, were also sites of unequal deposition. The determination of the direction of solution flow from a detailed study of one section of the wall in a cavity several feet or more in width could often be checked readily because bare places on the wall were noticeable when looking upstream against the postulated direction of flow. The same wall appeared to be covered with crystals when looking "downstream" along the flow direction. In considering the position of crystals on cavity walls it was noted that the size as well as the number of crystals on the stoss side of irregularities was greater. In cavities completely covered with crystals those on the stoss side were approximately two to five times larger in average diameter than crystals of the same mineral on the lea side.

Position of Crystal Overgrowths.—Overgrowths of one mineral on the stoss side of another mineral were a common source of evidence of solution movement direction (Fig. 4*C*). Marcasite on sphalerite, chalcopyrite on sphalerite, and chalcopyrite on dolomite were the most common overgrowths noted. Evidence also accumulated from a study of overgrowths of sphalerite on galena, marcasite on galena, marcasite on dolomite, calcite on galena, and quartz on sphalerite.

INTERPRETATION AND RELIABILITY OF THE DATA.

Measurement of the Horizontal Component.—Measurements of the horizontal component of asymmetry and location of overgrowth density were read to the nearest five degrees. Most of the determinations depended on several observations in the same cavity. The 159 determinations recorded resulted from several hundred observations. At most localities several criteria were used in determining a single recorded direction. Some of the determinations were the result of observations in a group of cavities within a distance of twenty feet. Where the criteria used were clearly developed, observations in the same cavity resulted in the same direction being recorded within plus or minus five degrees. Localities a few feet apart gave the same limit of vari-

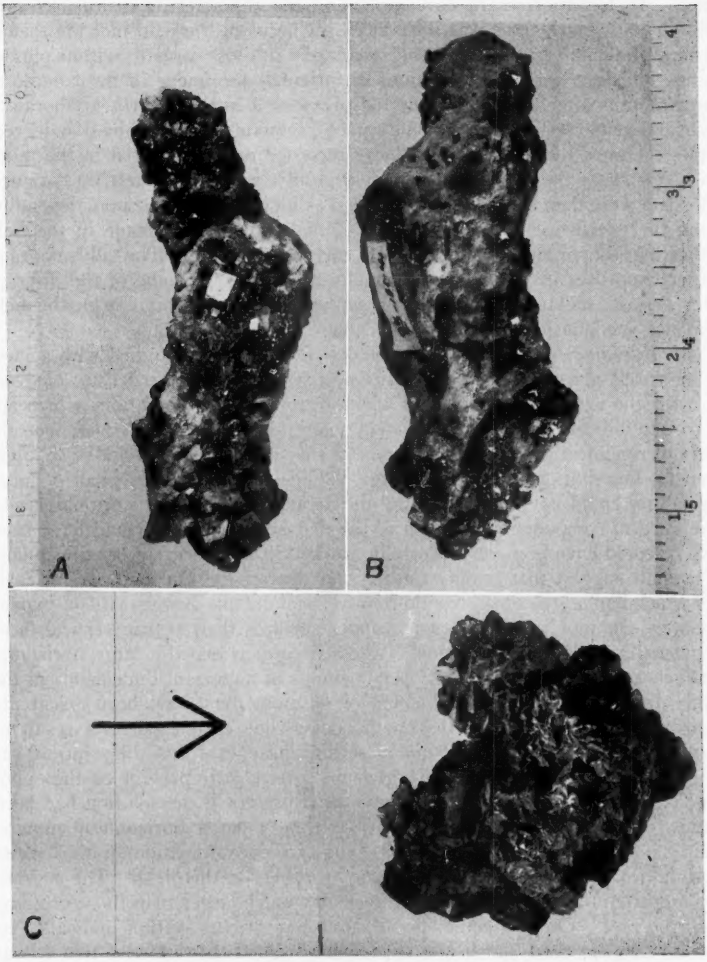


FIG. 4. *A*, galena and ruby blende on jasperoid from roof of a cavity in the Ohimo Mine. Looking in the postulated direction of the horizontal component of solution movement. *B*, same specimen looking "upstream," but on opposite side. Crystals of galena and ruby blende are fewer and smaller on this side. *C*, sphalerite crystal from floor of cavity in the Blue Goose Mine. Chalcopyrite crystals on the sphalerite are larger and more plentiful on the "upstream" side. Marcasite present only on this side. Arrow indicates postulated direction of horizontal component of solution movement.

ation. In localities where development of the characteristics measured was less obvious, more error was introduced. Checks in the field indicate that in general the data can be interpreted accurately in most cases to within plus or minus ten degrees. Determinations on oriented specimens in the laboratory three months after they were collected provided a further check. Laboratory measurements rarely differed by 10 degrees, sometimes differed by five degrees and sometimes were the same as those recorded on the material in the mine. In a few cases the laboratory and field results were completely at variance. The data were then discarded, or recorded as indicated in field notes, depending upon the excellence of the field data. Notation had been made in the field indicating the order of reliability of each observation. The advantage of larger exposures in the field undoubtedly accounted for some of the discrepancy between field and laboratory observations and for this reason the field evidence was considered more dependable.

Measurement of Vertical Component.—Crystals were studied with a view to interpreting from their form, position, asymmetry and the density of overgrowths the vertical component of solution flow. All observations which appeared to indicate a vertical component suggested a downward component but there were indications that at least some of this evidence should not be so interpreted. Gravitational settling of large colloidal particles or of small or large crystallites could have resulted in all the arrangements which were observed.[3] The vertical component of motion of the deposited solutions could have been zero or could have been very slowly upward. Several recurring arrangements of crystals suggest that gravity settling was operative. On the floors of cavities which had a greater horizontal than vertical extent, overgrowths of marcasite were commonly heavier on the upper surfaces than on the vertical faces of galena crystals. Examination of these cavities revealed a large horizontal channelway but no fractures or other openings of important dimensions in the roof. In these cavities the movement of solutions must have been essentially horizontal and the overgrowths on the upper side of the galena a result of gravitational settling. At the time of settling it appears that the solution was slowly moving for asymmetric overgrowths were clearly present on the opposite vertical faces which would not have been present if the solution had been static. Another suggestion of gravity settling from a horizontally moving solution during crystal formation is found from examination of the calcite crystals in the caves in the underground workings in this field. The crystals growing from the floor were almost invariably much larger than those growing from the roof. Only in some special cases was gravity settling indicated, as in the examples cited, but it seems probable from these examples that it was operative throughout the district during at least some part of the mineral-forming period.

RELATION OF SOLUTION MOVEMENT DIRECTIONS TO THE GEOLOGY OF THE FIELD.

Compilation of Data.—The horizontal component of the direction of solution flow inferred from the evidence described was plotted for each locality

[3] Newhouse, W. H.: op. cit., p. 621.

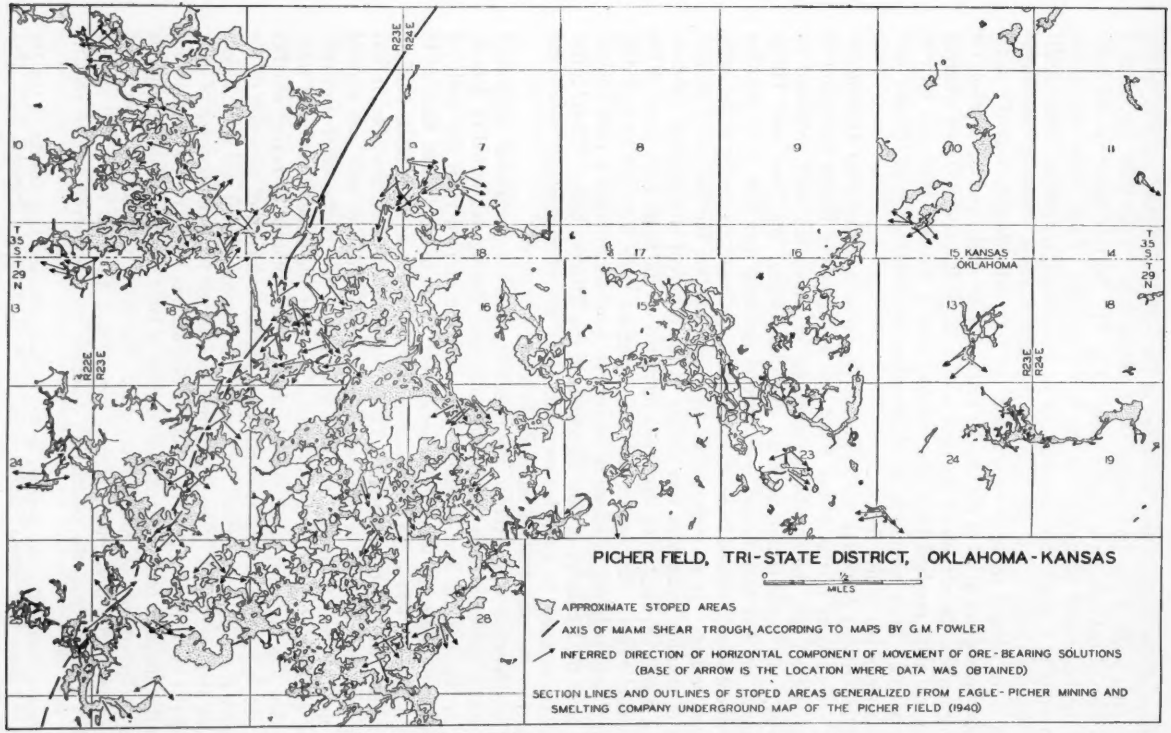

PICHER FIELD, TRI-STATE DISTRICT, OKLAHOMA-KANSAS
0 ½ 1
MILES
APPROXIMATE STOPED AREAS
AXIS OF MIAMI SHEAR TROUGH, ACCORDING TO MAPS BY G.M. FOWLER
INFERRED DIRECTION OF HORIZONTAL COMPONENT OF MOVEMENT OF ORE-BEARING SOLUTIONS (BASE OF ARROW IS THE LOCATION WHERE DATA WAS OBTAINED)
SECTION LINES AND OUTLINES OF STOPED AREAS GENERALIZED FROM EAGLE-PICHER MINING AND SMELTING COMPANY UNDERGROUND MAP OF THE PICHER FIELD (1940)
KANSAS
OKLAHOMA
R23E
R24E
R22E
T 35 S
T 29 N

FIG. 5. Map of stoped areas in Picher Field, Oklahoma-Kansas; stratigraphic position of the ore not indicated. All stoped areas are projected on the same plane. Arrows show the horizontal component of the direction of movement of the ore-depositing solutions as interpreted from observation of position and asymmetry of the ore minerals in cavities.

on maps of the underground workings of the individual mines, most of which were on a scale of one inch equals one hundred feet. They were also plotted on a map of the field on a smaller scale (Fig. 5). In this figure arrows indicate the horizontal component of the flow direction. Each arrow represents the results of a single determination or of several determinations from localities situated within a few feet apart in the same horizon. Several determinations were plotted together only when the inferred direction was the same within ten degrees at all of the nearby places. Like strike and dip symbols on geologic maps, the arrows on the map cover a large distance, 850 feet, whereas the actual data resulted from observations over a distance from one inch to twenty feet. Most commonly an observation represents study of crystals over a distance of one to five feet.

Similarity of Direction for Different Horizons and Different Minerals.—The ore deposits of the Picher Field are found in the Boone formation of Mississippian age, the detailed stratigraphy of which has been published by Fowler.[4] In some mines, such as the Blue Goose, Big John and Tulsa-Quapaw, ore has been mined from several ore beds and data as to solution movement were obtained from several horizons at locations nearly in the same vertical section. In an endeavor to determine whether the horizontal component of solution movement was similar in the different stratigraphic subdivisions, data from each were separately indicated on the large scale maps of the individual mines. Among the 159 determinations there were not enough data from closely adjacent locations in successive horizons to reach a valid conclusion as to the similarity of flow directions in the different beds. Where a few comparisons could be made between data from several mineralized beds in the same mine no consistent variation in direction was noted.

Consideration was given to the possibility that the horizontal component of solution movement might have been different during the period of deposition of one mineral and another. The evidence derived from the study of different ore minerals was plotted separately. Due to insufficient data, as in the similar case where the directions in different horizons were being studied, the results were not conclusive. To the extent data were available, it was clear that the information obtained from a consideration of only one mineral was not different from that obtained by study of any of the other minerals. More effective analysis of the problem of whether the same direction of solution flow was indicated by all the ore minerals was obtained by noting whether in a single location several minerals gave similar evidence of direction of the horizontal component of flow. A few of the instances noted will serve as examples and are typical. The flow direction inferred from the position of dark sphalerite crystals on a preferred side of undulations in the roof was in accord with the direction inferred from the position of later smaller sphalerite crystals on a preferred side of dolomite crystals. Marcasite crystals on a preferred side of sphalerite were interpreted as indicating a direction which was similar to that inferred from the position of dolomite on a preferred side of roof ir-

[4] Fowler, George M.: Ore Deposits in the Tri-State Zinc and Lead District in Ore Deposits as Related to Structural Features, edited by W. H. Newhouse, Princeton, N. J., 1942, pp. 206–207.

regularities. The latter determination was less rigorous, within plus or minus fifteen degrees as compared with the former which was recorded within plus or minus five degrees. Galena crystals growing on chert were interpreted as indicating a direction of solution flow which was the same as that interpreted from ruby sphalerite overgrowths on galena. Marcasite on dolomite and marcasite and chalcopyrite on sphalerite all gave the same evidence of solution movement direction and both galena and sphalerite grew on the same preferred side on knobs of chert in several localities. Marcasite overgrowth on galena and the uncentered lineage structure of galena both indicated the same direction but the latter could be interpreted much more exactly. From the results of these and similar observations it is concluded that in a single locality the evidence of different minerals as to horizontal component of solution flow is not contradictory. The characteristic of growth or position of one mineral was usually more specific than another but the extreme possibilities of direction of horizontal component of solution flow interpreted from the poorer evidence included the more exact direction interpreted from the better evidence. The sphalerite, galena, chalcopyrite, marcasite, ruby blende and probably crystals of dolomite appear to have been deposited from solutions which flowed with similar horizontal component of direction.

Calcite crystals in caves were not studied at every opportunity since these caves do not contain minerals of economic value. Most of the caves examined, however, showed a direction of solution movement similar to that indicated in nearly mineralized zones. To the extent to which data were compiled, solutions from which the calcite crystals were deposited followed directions similar to the sulphide-depositing solutions.

Regional Variation in Flow Direction.—As indicated on Fig. 5, in any area about the size of a quarter section, two quite different directions of flow are usually found. These directions can be considered as channels of flow extending in two opposite directions. The strikes of the channels are, for 90 per cent of the data, between N20W and N85W or between N30E and N80E. In some areas, particularly the center of the field, the strikes of the two channels are less than 90 degrees apart. Near the eastern and western limits of mining the two channels are more often at obtuse angles. In the field as a whole it appears that the channels of solution flow strike generally northeasterly and northwesterly. There is a variation within the area but much of the variation is of an orderly kind; the channels striking more nearly west occur near the eastern and western limits of the district. It seems reasonable to postulate that a northeast-northwest fracture system provided the channelways for the flow of mineralizing solutions. Structural evidence, chiefly the work of Fowler and Lyden,[5] supports this suggestion of a general structural pattern. Strong shear zones striking in northeasterly and northwesterly directions are described as important results of deformation in the Picher region. It may also be pertinent that many of the mineral-lined cavities observed in gathering the evidence of solution flow were elongated with the long axis coinciding with the channel direction although such coincidence was frequently

[5] Fowler, G. M., and Lyden, J. P.: Sequence of structural deformation in the Oklahoma mining field, Min. and Met. **15**: 415–418 (1934).

not established because the cavities were so largely broken away during mining. The observation suggests that at least some of the cavities were fractures enlarged prior to the deposition of the ore minerals by solutions moving in similar directions to the ore-forming solutions.

The major structural feature of the Picher district is the Miami shear trough. This is described by Fowler and Lyden[6] as consisting of a series of

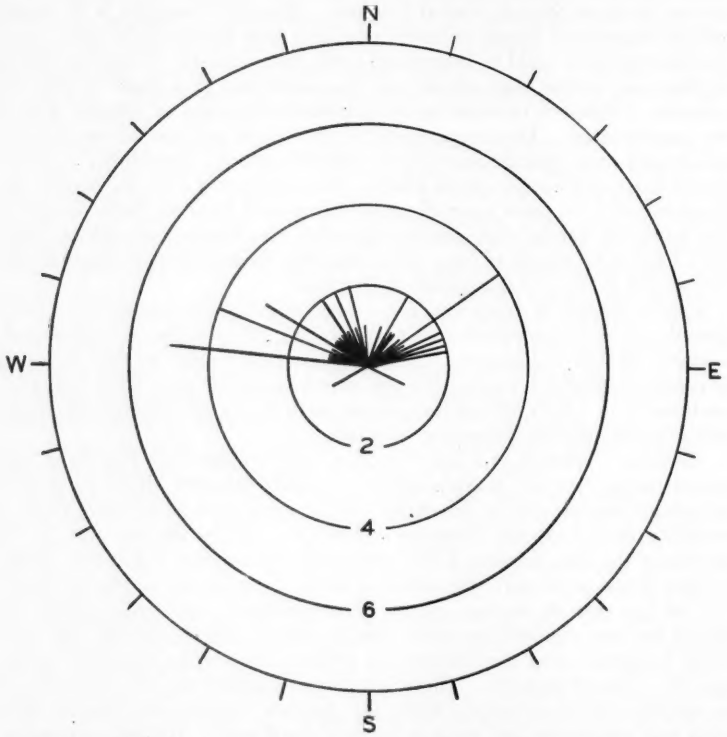


FIG. 6. Circular plot of determinations of horizontal component of solution movement direction in the area west of the Miami shear zone axis. Length of the radial lines indicates the number of similar determinations. Directions are expressed to the nearest five degrees.

elongated basins within a major trough in the surface of the Boone limestone. Strong fractures in this trough have a northeasterly trend. The trough is shown by structure contours on the M bed, a map of which has been published

[6] Fowler, George M., and Lyden, Joseph P.: The ore deposits of the tri-state district, Trans. A.I.M.E. **102**: 228 (1932).

by Fowler and Lyden.[7] The location of the axis of the trough was determined from this map and plotted on the map of the field, Fig. 5, which also shows the horizontal component of direction of flow. Examination of the data plotted shows that the movement of the solutions along the channels which have been discussed was southwesterly and southeasterly in the east and

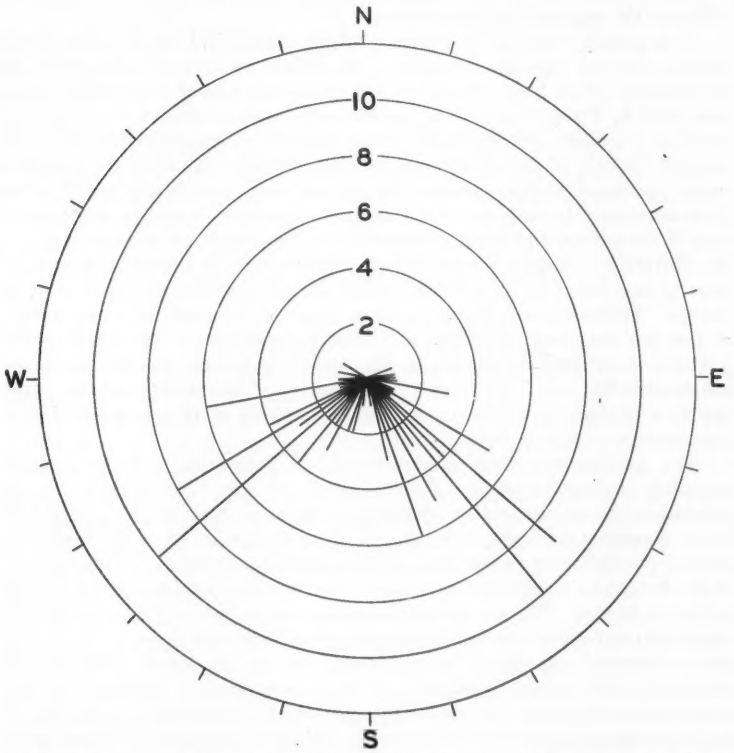


FIG. 7. Circular plot of determinations of horizontal component of solution movement direction in the area east of the Miami shear zone axis. Length of the radial lines indicates the number of similar determinations. Directions are expressed to the nearest five degrees.

central parts of the field and northeasterly and northwesterly in the western part of the area. The line of demarcation between the area of northerly and southerly flow directions is the axis of the Miami shear trough. The opposite direction of the horizontal component of flow is more strikingly indicated, together with the exceptions noted, in Figs. 6 and 7. Fig. 6 is a compilation of

[7] Fowler, G. M., and Lyden, J. P.: Sequence of structural deformation in the Oklahoma mining field, Min. and Met. 15: 416 (1934).

the directions located in the area to the east of the trough and Fig. 7 of directions determined which are located west of the trough axis. In each of the diagrams the directions of flow are plotted from a common center. The length of a radial line indicates the number of similar observations. Since the horizontal component of solution flow is opposite on the two sides of this structural axis it is concluded that the solutions spread from this major structure and followed the regional fracture system.

It is possible that the directions of flow in this field can be more closely tied in with the regional structure. The Miami shear zone axis strikes approximately N5 to 10E. Tensional fissures closely related to the shear trough are stated by Fowler and Lyden [8] to occur on opposite sides of the trough and are said to extend, striking north, across the echelon gaps between the northeasterly fissures in the trough. Since structures of this kind are present it would be expected that solutions leaving the shear trough might first follow these avenues. In such a case the solution movement would be south to the east of the trough and north to the west of the trough. Subsequent flow in the northeast-northwest fracture system would then be southeast and southwest to the east of the trough and northwest and northeast to the west of the trough. Without north-striking tension fractures to guide solutions initially as they left the trough, northeast and southeast might have been the directions followed in the fracture pattern to the east of the trough, and northwest and southeast to the west. Directions inferred from crystal studies are those compatible with the presence of tension fissures striking north giving initial guidance to the direction of flow.

The solution movement pattern should be compatible with observations regarding structural control of the ore bodies. Fowler [9] has described the ore deposits as being localized in structural troughs, on terraces, on minor folds in the bottoms of troughs, or in shears. The elongation of an ore body is in general parallel to the elongation of the localizing structure. The direction of the horizontal component of solution flow in many localities is not parallel to the ore bodies. The ore solutions appear to have followed the channelways described until the channelways intersected favorable structures or themselves became favorable for deposition and there ore was deposited. Whether the structures were favorable because of the pressures there existing, or were zones containing waters which, mingling with the mineralizing solutions, effected precipitation, or were in some other respects favorable for deposition is beyond the scope of this study.

DARTMOUTH COLLEGE,
HANOVER, N. H.,
August 1, 1946.

[8] Fowler, G. M., and Lyden, J. P.: The ore deposits of the Tri-State District, Trans. A.I.M.E. **102**: 236 (1932).

[9] Fowler, G. M.: Tri-state geology, Eng. and Min. Jour. **144**: No. 11, 78 (1943).

LUMINESCENT PHENOMENA AS AIDES IN THE LOCALIZATION OF MINERALS IN POLISHED SECTIONS.[1]

HERMAN YAGODA.

ABSTRACT.

The construction of a simple ultraviolet illuminator for the observation and photomicrography of fluorescence reactions on polished surfaces is described. The relative intensity and distribution of phosphorescing components are recorded by contacting the irradiated section against photographic emulsions. An exact replica of the fleeting phosphoresence is secured by the use of color sensitive film as the contact medium. The methods are serviceable in securing contrast between different components of the section and facilitate their identification by auxiliary tests.

INTRODUCTION.

NUMEROUS non-opaque solids transform the energy of electromagnetic radiations, or atomic particles, into radiation of lower frequency. When the wavelength of the emitted radiation falls within the range of normal vision the phenomenon is termed fluorescence, and photoluminescence when the radiations reside below the purple threshold of vision. On the removal of the source of excitation certain crystalline solids continue to emit light for varying periods, the phosphorescent radiations residing either in the visible, the near ultraviolet or both. In this study of luminescent phenomena the description will be limited to excitation reactions produced by ultraviolet light of predominantly 2,537Å wavelength.

The luminescence of a mineral is not a simple function of its fundamental molecular composition, but is also dependent on the presence and relative abundance of minor quantities of activating ions held in solid solution. Thus, pure zinc silicate does not fluoresce, but if a minute quantity of manganese is incorporated, the solid solution exhibits a brilliant green luminescence on irradiation. The manganese activated compound is of common natural occurrence, but it must be emphasized that the fluoresence is not a definitive analytical reaction for willemite as the mineral also occurs with either no manganese or else in too great excess for the production of the fluorescing system. In general, the luminescent reactions of minerals activated by trace constituents are not conclusive means of identification. The utility of the ultraviolet illumination resides in the extreme contrast provided by the colored light emitted by the phosphor which facilitates its isolation for study by other methods.

[1] Paper presented before the Society of Economic Geologists, Pittsburgh meeting, December 1945.

Luminescent reactions are also produced in pure solids which contain certain ionic groupings as UO_2^{++}, WO_4^{++} and MoO_4^{++}. This minor group of phosphors is serviceable in the localization of certain secondary uranium minerals [2] and in the estimation of the molybdenum content of scheelite.[3] The presence of the UO_2^{++} group renders the mineral fluorescent provided quenching atoms are absent from the crystal lattice. Thus, autunite, $CaO \cdot 2UO_2 \cdot P_2O_5 \cdot 8H_2O$, fluoresces a brilliant yellowish green, but the copper analogue torbernite, $CuO \cdot 2UO_2 \cdot P_2O_5 \cdot 8H_2O$, is non-fluorescent.[4]

The methods of fluorescence microscopy commonly employed in the examination of histological sections using transmitted long wavelength ultraviolet light are not applicable to thin sections of rocks. Most mineral phosphors are activated by short wavelength ultraviolet light, and this illuminant is completely absorbed by the glass slide and mounting media. Vertical illumination of polished sections with 2,537Å radiation is not practical as it necessitates the use of a quartz optical system assembled from non-fluorescent materials. An annular oblique ultraviolet illuminator has been described [5] for use in the localization of fluorescent dust particles in microincinerated lung tissue. This lamp is also suitable for the observation of the fluorescence pattern of phosphors in thin sections mounted without cover glass. The annular construction of the illuminator, however, does not permit removal of samples during illumination. A lamp more suitable for mineralographic manipulation can be assembled from readily available standard parts, and its proven utility merits description.

THE FLUORESCENT PATTERN.

The illuminating system for observing a polished section under visible and ultraviolet light is described in Fig. 1. The source of 2,537Å radiation consists of a 4 watt U-shaped General Electric Germicidal Lamp enclosed in an aluminum tube fitted with a 1 mm. thick Corning 986 red purple Corex A glass filter. The lamp operates on 110 volt AC line in circuit with a 4 watt ballast and starter unit (Cat. No. 58G825). Very little heat is developed by the lamp even after long periods of operation so that it can be placed in close proximity to the specimen and objective. When used in conjunction with a long working distance objective ($6\times - 0.17$NA, 22.7 mm. achromate) sufficient light is provided for the visual observation of brilliantly fluorescing mineral grains at magnifications up to 150 diameters. The oculars (5 to 25 $\times$) should be fitted with a disk of Wratten gelatin filter No. 2A as a protection from reflected ultraviolet light during visual observation and to prevent fogging of the emulsion in photomicrography. The red-purple Corex filter

[2] Meixner, H.: Fluoreszenzanalytische, optische und chemische Beobachtungen an Uranmineralen, Chem. Erde 12: 433–50 (1940).

[3] Cannon, Jr., R. S., and Murata, K. J.: U. S. Pat. 2,346,661, Apr. 18 (1944).

[4] Certain tabulations of fluorescent minerals list torbernite as fluorescing green. Microscopic examination of numerous polished sections of this mineral proves it to be non-fluorescent. Torbernite is often associated with coatings of autunite which imparts fluorescence to the massive sample.

[5] Yagoda, H., and Donahue, D. D.: Fluorescent mineral dusts as tracers for the localization of particles in tissue. J. Ind. Hyg. Tox. 27: 193–98 (1945).

also transmits a small fraction of the 4,200–4,000Å radiations generated by the lamp. This produces a residual purple field which diminishes the contrast of inclusions fluorescing with a predominantly blue color. This situation is remedied by employing an Aero No. 1 gelatin filter in the ocular.

The comparative appearance of the section under visible light is effected either by vertical illumination or by means of an auxiliary incident illuminator. By diminishing the intensity of the white light with the aid of an opal glass it is possible to observe the fluorescence of individual grains in relation to the components of the non-fluorescing matrix. The No. 2A gelatin filter does

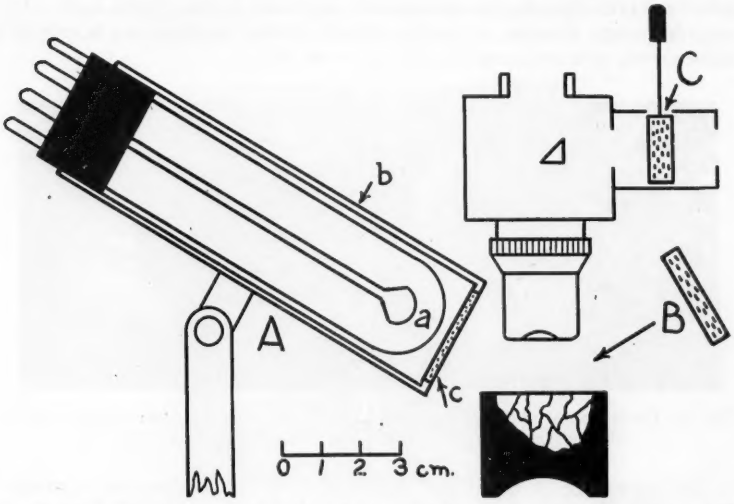


FIG. 1. Illuminating system for microscopic observation of fluorescence. (*A*) Source of filtered 2,537Å radiation consisting of germicidal lamp (*a*) enclosed in an aluminum tube (*b*) supporting a 1 mm. 986 Corex A red purple filter (*c*). (*B*) Auxiliary tungsten filament lamp for incident illumination by white light and 3,800Å ultraviolet by means of a 5 mm. 586 Corning glass filter. (*C*) Vertical illuminator for observation of metallic minerals by white light showing disc of 586 glass for securing long wavelength ultraviolet light from tungsten filament lamp.

not interfere with the observation by visible light, but the yellow colored Aero No. 1 filter must be removed from the ocular, particularly in the photography of red fluorescing inclusions.

The insertion of a Corning 586 glass filter over the condensing lens of the oblique white light illuminator provides a convenient source of long wavelength (3,800–3,600Å) ultraviolet light. By converging the beam from the tungsten filament onto the section, prefocused with the aid of white light, the filter transmits sufficient ultraviolet for visual fluorescence observations at magnifications up to 30 diameters. This auxiliary source is useful in the visual localization of minerals whose luminescence is not excited by 2,537Å

radiation, as sodalite and certain fluorites. A small disk of this glass, of the same dimensions as the polarizing disk of the vertical illuminator, also provides another simple source of long wavelength ultraviolet light. Greater intensity is secured when the filter is employed in conjunction with a prism vertical illuminator.

The intensity of the fluorescent light is in general low, necessitating long exposures in order to secure photomicrographs of suitable density. The period of exposure can be reduced by the use of high speed emulsions. Better definition is secured using emulsions of moderate speed (Eastman Process Panchromatic). At a magnification of 50 × these require an exposure of 15–45 minutes depending on the intensity and color of the emitted light. The recorded image, however, is sharply defined and the negatives can be enlarged subsequently to a total magnification of about 200 ×.

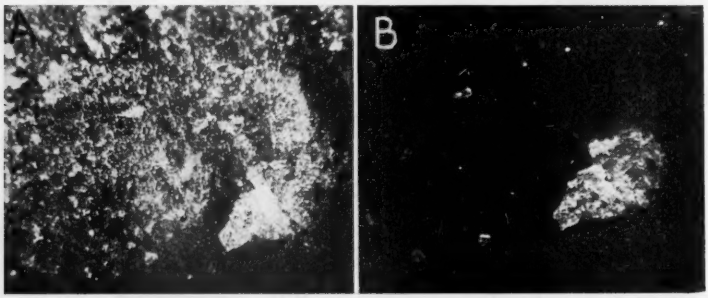


FIG. 2. Comparative photomicrographs (50 ×) of scheelite grains under visible oblique light (*A*) and incident 2,537Å illumination (*B*).

The advantage of ultraviolet illumination in the localization of minute grains (400–10 microns) of scheelite in a complex groundmass of silicates and opaque minerals is exhibited by the comparative (Fig. 2) visual and ultraviolet patterns. The fluorescence produced by ultraviolet illumination serves as a transitory stain providing contrast between the components of the section. While the colors may be useful as indications of certain groups of minerals,[6] the final identification must be made by other petrographic techniques.

THE PHOSPHORESCENCE PATTERN.

When the phosphorescence is of sufficient intensity and duration a record of the phenomenon can be secured by contacting the specimen immediately after its excitation with a photographic emulsion. Autoluminographs produced by this simple mechanism have been described by Baskerville [7] and have

[6] The luminescent reactions of minerals from different localities are tabulated in publications by C. Palache, Amer. Min. 13: 330 (1928); E. S. C. Smith and W. H. Parsons, Amer. Min. 23: 513 (1938); M. A. Northup and O. I. Lee, J. Opt. Soc. Amer. 30: 206–223 (1940).

[7] Baskerville, C., and Kunz, G. F.: Kunzite and its unique properties. Amer. J. Sci. 18: 25 (1904).

found extensive application in the study of the photoluminescence of fluorites by Iimori [8] and Brown.[9]

The phosphorescence is induced by direct exposure to the unfiltered radiations from a mercury vapor lamp. It is convenient to replace the filter with a black shield having a centered hole in which the mounted specimen is inserted during irradiation. A period of about 1 minute suffices for excitation, and 15 sec. to 5 min. is representative of the exposure range against the emulsion. Conditions for optimum rendition of detail vary with the specimen and must be approximated by successive trials. Fast blue sensitive emulsions (Eastman type I–O) will record feeble phosphorescent reactions and are of most general applicability as a major fraction of the emitted radiations often reside below 4,000Å. A panchromatic emulsion is desirable when the phosphorescent light resides in the visible. Positive prints from typical phosphorescent patterns are reproduced in Fig. 3.

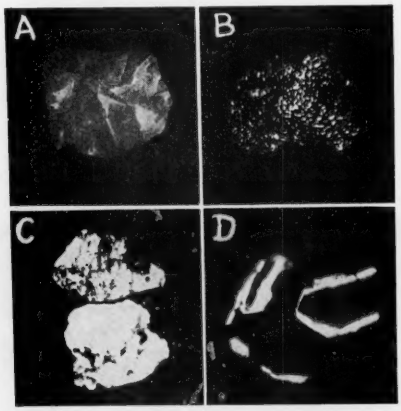


FIG. 3. Autoluminographs of phosphorescent minerals. (*A*) Single crystal of scheelite, Bolivia, S. A.; (*B*) Sphalerite grains in matrix of copper sulfide minerals, Tsumeb, S. W. Africa; (*C*) Calcium larsenite (white) and willemite (gray), Franklin, N. J.; (*D*) Barite crystals in limonite, Georgia. Note concentration of activator along crystal edges.

When the phosphorescence resides in the visible and is of appreciable duration and intensity a permanent record is secured by contacting the irradiated surface with color sensitive film. This novel technique has been applied successfully in the study of the phosphorescent areas of specimens containing willemite, clinohedrite, hardystonite, wernerite, sphalerite and calcite. Fig. 4 shows a series of autoluminographs of a polished slab of ore from

[8] Iimori, S., and Iwase, E.: The solarization of fluorite, and the law of lumino transformation. Sci. Papers Inst. Phys. Chem. Res., Tokyo 16: 41–67 (1931).

[9] Brown, W. L.: Photo-phosphorescence in minerals. Univ. Toronto Studies, Geological Series, No. 35, 19–35 (1933).

the Franklin, N. J., zinc deposits on emulsions of varying color sensitivity. The matrix composed essentially of hardystonite—$Ca_2ZnSi_2O_7$ exhibits a persistent phosphorescence (*B*) which is not evident by visual inspection of the irradiated specimen. On color sensitive film the hardystonite registers a blue image. The section also contains streaks of clinohedrite—$H_2CaZnSiO_5$ and grains of willemite—$(Zn,Mn)_2SiO_4$ whose phosphorescent patterns are recorded by a panchromatic emulsion (*C*). On color sensitive film these minerals produce orange and green colored images, respectively. The correct width of the clinohedrite inclusions is exhibited only where the veins pene-

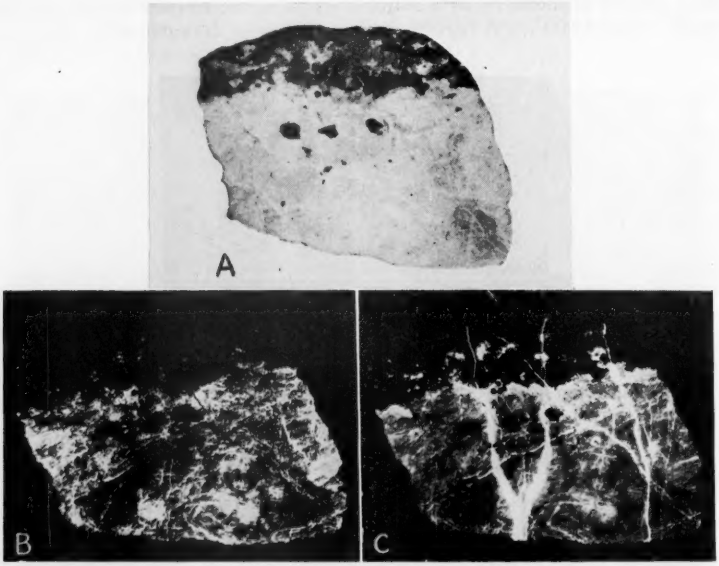
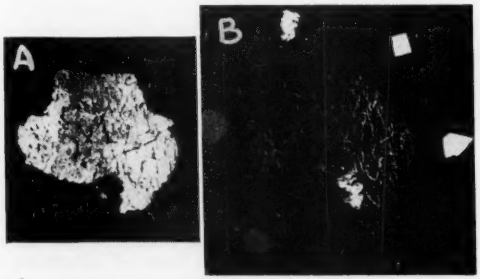


FIG. 4. Autoluminographs of Franklin, N. J., zinc ore. Positive prints (1 ×), white represents persistent phosphorescence, gray phosphorescence of lesser intensity or brief duration. (*A*) Section under incident white light. (*B*) Autoluminograph on orthochromatic emulsion. (*C*) Autoluminograph on panchromatic emulsion.

trate the opaque franklinite, the broadening of the image in the lower portions is caused by scattered light from the adjacent translucent minerals.

The replica of the phosphorescence on color film has proven of utility in determining the color of the emitted light when the emission occurs in spectral regions of low visual sensitivity. Thus, scheelite, which is commonly described as non-phosphorescent when the response is tested visually, develops a blue colored image. Likewise, the phosphorescent fluorites (antozonite) form dark purple images on the color film.

The autoluminographs on photographic media are specific for the luminescence phenomena. The brief period of contact avoids interference by radioactive radiations from uranium and thorium minerals. The latter require an exposure of several hours for the production of a developable latent image. Comparative autoluminographs and alpha ray emission patterns [10] of a specimen containing phosphorescent and radioactive inclusions are reproduced in Fig. 5. The autoluminograph is a replica of a complex phosphor-activator



STATE COLLEGE OF AGRICULTURE AND APPLIED SCIENCE
LIBRARY
JAN 9 1947
MANHATTAN
KANSAS

FIG. 5. Comparison of autoluminograph and alpha ray patterns of a specimen from pegmatite of Spruce Pine, N. C., containing feldspar, columbite and inclusions of uranophane. Positive prints (1 ×). (*A*) Autoluminograph on type I–O emulsion, exposure 10 sec. Feldspar (white), columbite (gray), uranophane (black). (*B*) Autoradiograph on fine grain alpha ray emulsion, exposure 195 hours. The surrounding images were produced by minerals of known alpha ray activity. Note that radioactive uranophane inclusions (white) do not produce an interfering image on (*A*).

system and is of direct analytical significance only as a means of exhibiting variations of composition in regions of the specimen which appear optically homogeneous. The autoluminographic mechanism is thus a preliminary step in the localization of certain trace constituents serving as activators whose identity can in certain cases be ascertained by application of chemical printing techniques.[11]

ACKNOWLEDGMENTS.

It is a pleasure to express the aid received from O. I. Lee in providing the writer with chips of fluorescing minerals from his private collection, which were employed in the preparation of polished sections.

NATIONAL INSTITUTE OF HEALTH,
INDUSTRIAL HYGIENE RESEARCH LABORATORY,
BETHESDA, MD.,
August 1, 1946.

[10] Yagoda, H.: The localization of uranium and thorium minerals in polished section. Amer. Min. 31: 87–124 (1946).

[11] Yagoda, H.: The localization of copper and silver sulfide minerals in polished sections by the potassium cyanide etch pattern. Amer. Min. 30: 51–64 (1945).

HYDROTHERMAL ALTERATION IN THE CASTLE DOME COPPER DEPOSIT, ARIZONA.[1]

N. P. PETERSON, C. M. GILBERT, AND G. L. QUICK.

ABSTRACT.

Hydrothermal alteration of the quartz monzonite host rock in the Castle Dome copper deposit consists of three phases. Very weak propylitic alteration of biotite and plagioclase occurs in the marginal part of the mineralized area. Where mineralization is stronger most of the plagioclase and some of the orthoclase and biotite are replaced by a montmorillonite-type clay, resembling beidellite, and hydrous mica. The third phase is localized along quartz-pyrite veins where the wall rock, commonly as much as an inch from the vein, is replaced by quartz and sericite. In contrast to the localization of quartz-sericite alteration along the veins, clay alteration is general and can be seen between the veins wherever the rock is not completely sericitized. Thus these two types of alteration cannot be separated areally. The most intense clay alteration together with moderate quartz-sericite alteration occurs in the ore body, whereas the strongest quartz-sericite alteration, where pyrite veins are largest and most numerous, is in a zone along the north side of the ore body.

INTRODUCTION.

THE Castle Dome copper deposit is in the Miami mining district, Gila County, Arizona, 7 miles west of Miami. The Castle Dome open cut mine on the south flank of Porphyry Mountain is owned and operated by the Castle Dome Copper Company, Inc., a subsidiary of the Miami Copper Company. It was developed by the owners as a war project, and since June, 1943 has produced about 4,000,000 pounds of copper per month.

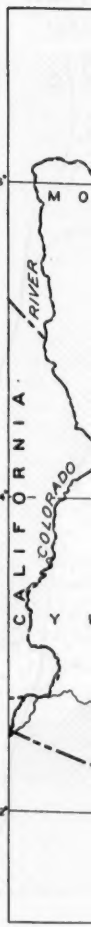
The general geology of the Globe quadrangle (Fig. 1), which includes the Castle Dome area, was studied by F. L. Ransome[2] in 1901 and 1902, and an account of the Miami-Inspiration copper deposit by Ransome[3] was published in 1919. The present study in much greater detail was carried on by the Geological Survey during the period from July, 1943 to September, 1944 and was confined to the area surrounding the Castle Dome mine. Fig. 2 is a generalized geologic map of the area compiled from a detailed map on a scale of 1:2,400.

We wish to acknowledge the cordial co-operation of the staff of the Castle Dome Copper Company, especially R. W. Hughes, Manager, B. R. Coil, General Superintendent, and J. C. Van de Water, Mine Superintendent. We received suggestions from many of our colleagues in the Geological Survey. We

[1] Published by permission of the Director, Geological Survey. Presented before the Society of Economic Geologists. Pittsburgh Meeting, Dec., 1945.

[2] U. S. Geol. Surv. Prof. Paper 12, 1903.

[3] U. S. Geol. Surv. Prof. Paper 115.



are particularly indebted to C. S. Ross, B. S. Butler and T. S. Lovering for valuable assistance and advice. Thanks are also due Adolf Pabst for criticism of this paper.

GENERAL GEOLOGY.

The copper deposit occurs in a body of quartz monzonite intruded into Pinal schist and Apache group of pre-Cambrian age and possibly into the

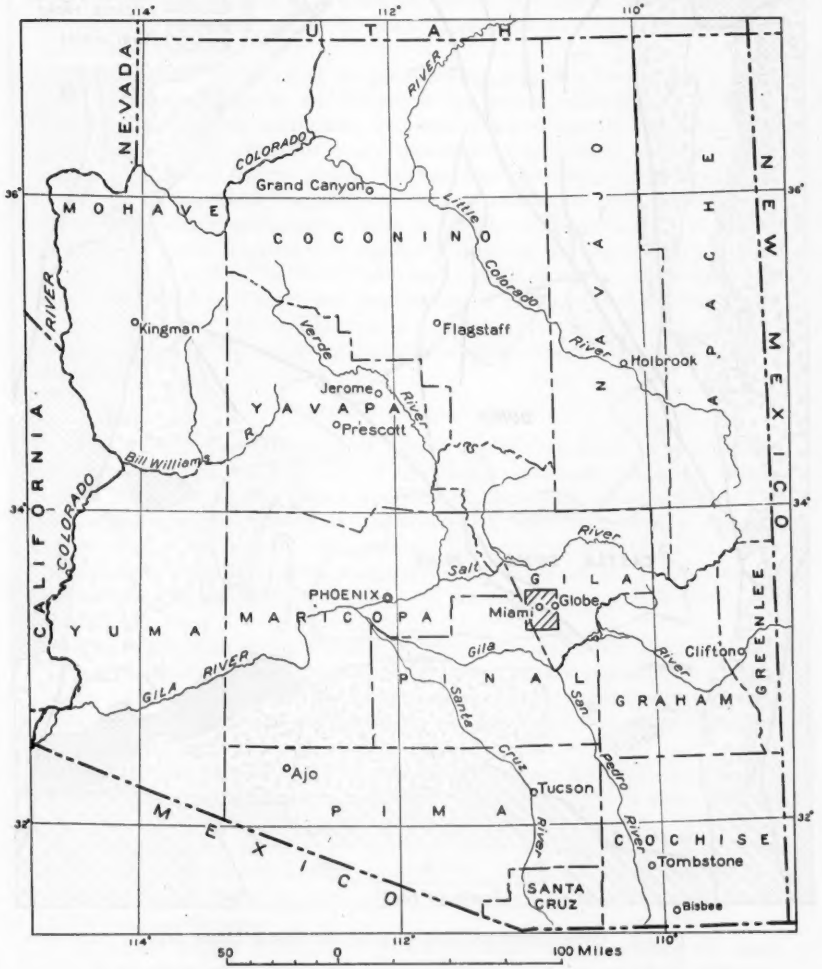


FIG. 1. Index map of Arizona showing location of the Globe quadrangle.

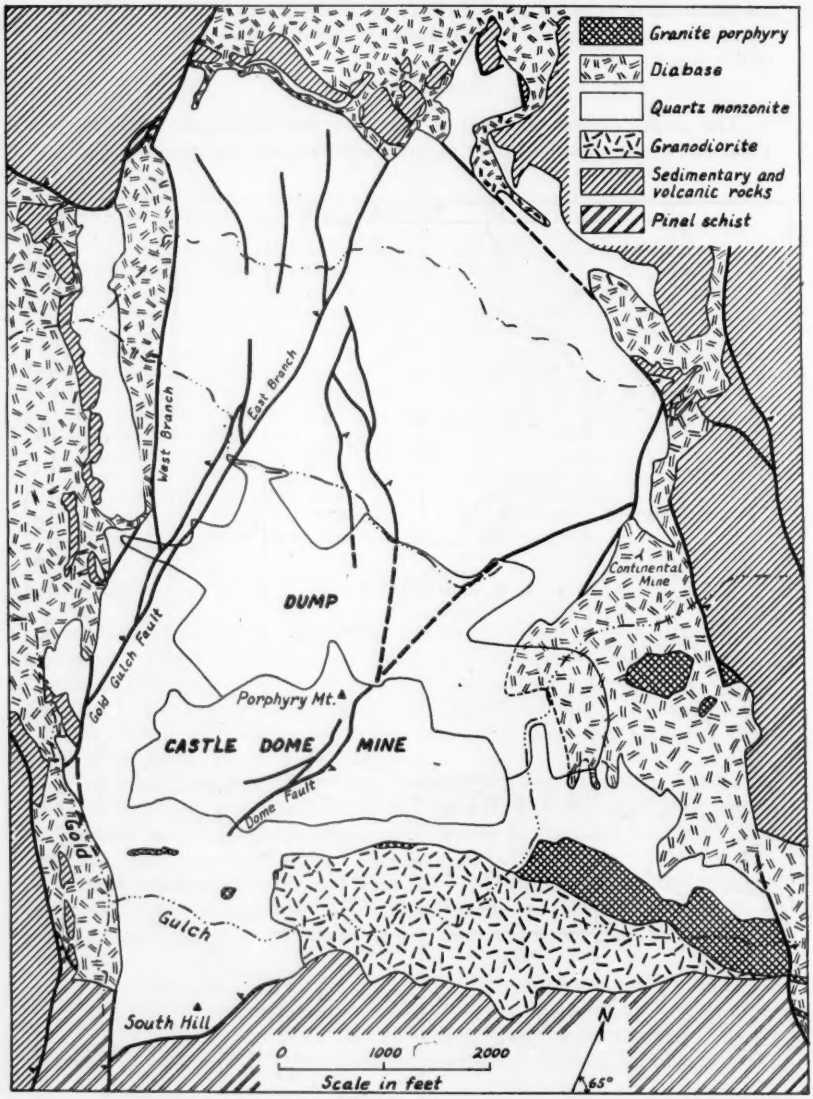


FIG. 2. Generalized geologic map of the Castle Dome area.

lower part of Paleozoic limestones (Fig. 1). The quartz monzonite was preceded by a small intrusion of granodiorite which crops out along its south side. Following the quartz monzonite intrusion the area was cut by normal faults, and large volumes of diabase were injected as thick sills and dikes. Small bodies of granite porphyry were later intruded mainly along the south edge of the quartz monzonite. In late Tertiary time the region was covered by a thick flow of dacite lavas. Following the dacite eruption, erosion again exposed the older rocks in some areas, in others Gila conglomerate accumulated as valley fill. Probably all of the Castle Dome area was low and covered by Gila at that time.

The dominant structure of the Castle Dome area is a horst trending in a north-northwest direction, and within it the quartz monzonite is confined. The horst is bounded on the east and west sides by steeply-dipping normal fault systems along which the quartz monzonite was brought in fault contact with Paleozoic and Apache rocks. Diabase was intruded along the marginal faults and now generally separates the quartz monzonite from the relatively depressed blocks of sedimentary rocks on the east and west sides. A second and smaller horst, trending in a northerly direction, is bounded on the west by the East Branch of the Gold Gulch fault, which dips west, and on the east by the east-dipping Dome fault system and a group of east-dipping faults north of the mine. Normal faulting occurred at intervals until early Quaternary time, and all formations of the region except recent alluvium have been displaced.

HYPOGENE METALLIZATION.

The hypogene metallization is almost entirely confined to the granite porphyry and the southern half of the quartz monzonite body. It occurs mainly in narrow, closely spaced, generally parallel veins, which strike N. 75° E. and dip steeply southward, but some sulphides are disseminated in the wall rock between the veins. The principal hypogene vein minerals in order of abundance are quartz, pyrite, chalcopyrite and molybdenite. A few younger veins containing sphalerite and galena cut across the pyrite, chalcopyrite and molybdenite veins.

The distribution of the primary sulphide minerals shows distinct zoning. The zones trend parallel to the strike of the veins and are probably also parallel in dip. One zone, in which the mineralization is mainly pyrite with very little chalcopyrite (0.01 to 0.15 per cent Cu), extends across the quartz monzonite through the summit of Porphyry Mountain (Fig. 3).

Northward the mineralization in this zone decreases gradually to where it is no longer recognizable in the outcrops. South of the pyrite zone and parallel to it is a zone containing less pyrite and more chalcopyrite. The hypogene mineralization in this zone is estimated to average about 0.3 per cent copper and is the protore of the ore body. Molybdenite is most abundant in a zone which overlaps the southern edge of the pyrite zone and the northern edge of the chalcopyrite zone.

A second smaller zone of high pyrite metallization occurs along the north side of the fault which forms the contact between the schist and quartz mon-

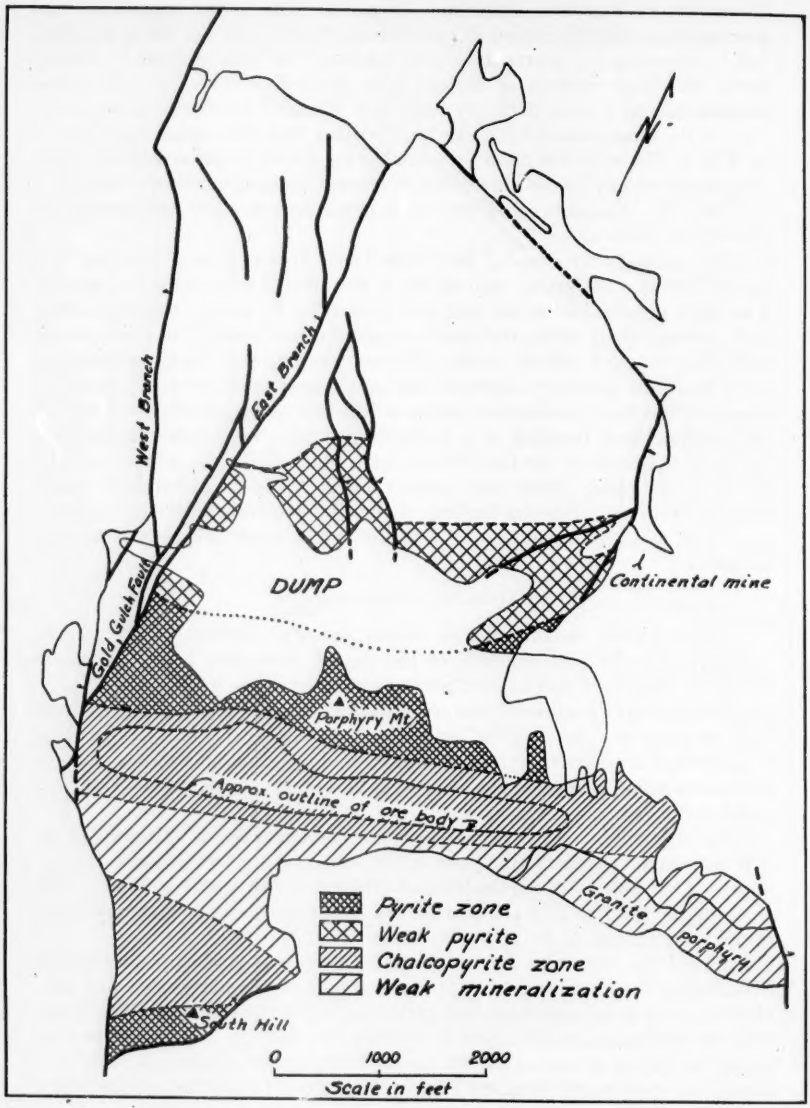


FIG. 3. Outline of the quartz monzonite showing generalized pattern of hypogene mineralization.

zonite on the south side of South Hill at the southwest corner of the quartz monzonite body (Figs. 2 and 3). This high pyrite zone is flanked on the north by a chalcopyrite zone in which a small ore body has been produced by supergene enrichment.

Several thin, fine-grained diabase sills crop out along the south side of the main ore body and dip gently northward through the mine. The copper content of the rock is invariably higher than average in and near these sills.

The quartz monzonite is much older than the mineralization and served merely as host rock. Hypogene mineralization was more nearly contemporaneous with the granite porphyry intrusions than with any other igneous rock of the region and is therefore probably genetically related to the porphyry. The association of copper mineralization with granite porphyry intrusions is characteristic of the Miami district. In each of the major mineralized areas of the district granite porphyry is present and is mineralized, but the main ore bodies occur in the adjacent rocks which are either schist or quartz monzonite.

The Castle Dome ore body is the result partly of supergene enrichment and partly of the richer hypogene mineralization associated with the diabase sills. A leached capping, which averages about 80 feet thick and generally contains less than 0.1 per cent copper, overlies the ore body. Except for the copper enrichment of the hypogene chalcopyrite and pyrite, the supergene alteration has not greatly affected the products of hydrothermal alteration.

THE QUARTZ MONZONITE HOST ROCK.

The quartz monzonite has a generally uniform mineral composition, essentially quartz, orthoclase and oligoclase. Subhedral books of dark brown biotite, commonly including oriented needles of rutile, are characteristic of the rock but are not abundant. Minor accessory minerals are zircon, apatite, sphene and ilmenite. Zircon is decidedly rare and occurs in very small crystals, whereas the others are more common and generally are clustered near the biotite crystals. The orthoclase is evenly distributed throughout the quartz monzonite as large pink or reddish brown microperthitic phenocrysts having an almost equant form ranging from 1 to 3 inches across. Most of them poikilitically enclose small oligoclase crystals in a zonal arrangement, and some have rims of oligoclase (rapakivi structure). Without exception the phenocrysts rimmed by oligoclase have round or oval cross-sections, whereas the unrimmed phenocrysts are euhedral.

Although the general composition of the rock appears to be uniform throughout the map area, there are some local variations in the relative amounts of the essential minerals so that here and there the rock might be called granite on the one hand or granodiorite on the other.

Two widespread textural varieties have been distinguished and separately mapped, but although they differ in texture the mineral composition of the two is approximately the same. One variety is porphyritic quartz monzonite containing large phenocrysts of pink or reddish orthoclase in a coarse-grained groundmass, the other is quartz monzonite porphyry containing phenocrysts of orthoclase, quartz, oligoclase and biotite in a fine-grained groundmass.

The contact between them is sharp in many places; elsewhere it seems gradational but is generally definite outside the area of most intense hydrothermal alteration. Quartz monzonite porphyry occurs in the central part of the Porphyry Mountain area and is nearly surrounded by the porphyritic quartz monzonite. The two phases probably represent intrusive pulses of the same magma, the porphyry being slightly younger.

No appreciable difference in either mineralization or hydrothermal alteration is recognizable in adjacent bodies of the two phases of quartz monzonite.

HYDROTHERMAL ALTERATION OF THE HOST ROCK.

General Description.—The hydrothermal alteration that accompanied the copper mineralization in the Castle Dome area consists of three phases (Fig. 4). A very mild phase of the propylitic type, in which biotite and plagioclase are partly altered to sericite, epidote, clinozoisite, chlorite and calcite, occurs in an outer zone where mineralization is very weak, and extends beyond the area where mineralization and alteration can be recognized in the field. This zone surrounds an area of stronger alteration where most of the plagioclase and a little of the orthoclase and biotite are replaced by a montmorillonite-type clay. The clay or argillic [4] phase of alteration is most intense in the mine area and diminishes gradually toward the north and south where more fresh plagioclase together with the alteration products of the propylitic phase is evident. The third phase of alteration, which will be referred to as the quartz-sericite phase, is related to numerous small quartz-pyrite veins along which the wall rock is replaced by quartz, sericite and a little pyrite and adularia. Each quartz-pyrite vein is bordered by a white zone from a fraction of an inch to several inches wide where the wall rock has been mostly replaced by quartz and sericite. Although veins bordered by quartz-sericite alteration occur throughout the mineralized area, they are most numerous, largest, and have the widest alteration borders near the summit of Porphyry Mountain. This area of most intense quartz-sericite alteration is entirely within the clay zone and might be said to represent a third and inner zone of alteration. However, clay alteration is strong in the wall rock between the veins and the two phases cannot be separated areally. Thus although quartz-sericite alteration should be regarded as a separate phase it is superimposed on the clay phase as well as the propylitic phase and actually does not constitute a separate zone.

Propylitic Alteration.—In the marginal part of the mineralized area, entirely outside the mine, the host rock shows the effects of very weak alteration which produced minerals characteristic of propylitization. So feeble is the alteration that the rock, in hand specimens, looks fresh except for a slight greenish coloration of the biotite due to replacement by chlorite. The minerals produced during this phase of alteration are seen under the microscope to include pyrite, chlorite, epidote, clinozoisite, sericite, calcite, and leucoxene, but

[4] Term used by Lovering to describe the effects of hydrothremal alteration that has resulted in the prominent development of clay minerals. Lovering, T. S.: The origin of the tungsten ores of Boulder County, Colorado. ECON. GEOL. 36: 236, 1941.

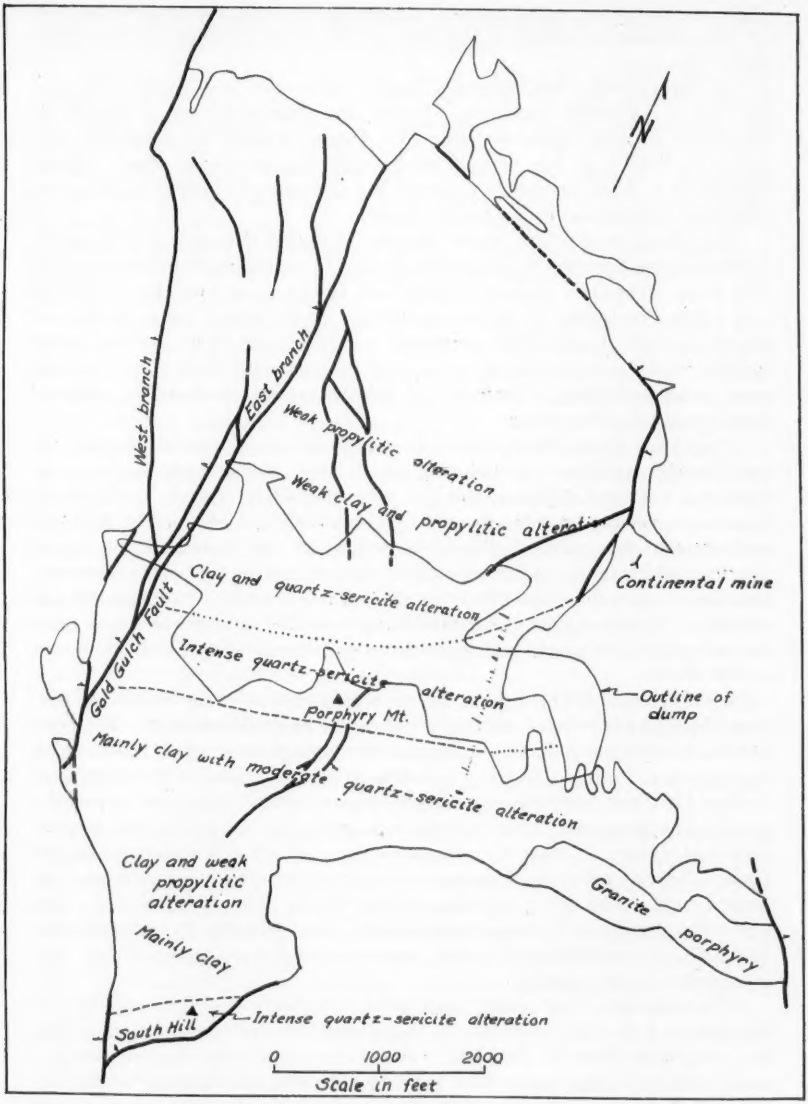


FIG. 4. Outline of the quartz monzonite showing general distribution of alteration phases.

their occurrence and small amount suggest that they are the result essentially of recrystallization without appreciable change in the bulk chemical composition of the rock.

Of the original rock minerals, quartz, orthoclase, and apatite were not affected by propylitic alteration. Biotite and plagioclase are invariably altered but nowhere completely replaced. Sphene is partly or completely converted to leucoxene, but ilmenite shows only thin leucoxene rims. Sphene apparently is most susceptible to attack and is commonly altered to leucoxene where the other minerals are largely fresh.

Commonly most of the biotite remains unaltered but some of it is partly replaced along cleavages by green chlorite having anomalous blue birefringence, and a few completely replaced crystals are chlorite pseudomorphs. Epidote and a little clinozoisite, in addition to chlorite, partly replace some biotite, and where they are absent calcite commonly occurs. Some of the oriented rutile needles which form inclusions in most of the unaltered biotite, and possibly some small inclusions of ilmenite and sphene, are recrystallized to scattered rutile granules or leucoxene.

Plagioclase invariably contains plates and veinlets of sericite oriented approximately parallel to the twinning plane (010) and at right angles to it. Sericite is scattered uniformly through some plagioclase crystals, but in others it occurs in patches here and there. It is commonly accompanied by stringers and scattered tiny grains of clinozoisite or epidote. In contrast to the altered biotite in which more epidote than clinozoisite occurs, altered plagioclase contains much more clinozoisite than epidote. A few crystals are replaced almost completely by clinozoisite. A little chlorite in veinlets and as rosettes is present in some of the plagioclase, and where epidote and clinozoisite are absent calcite occurs.

Clay Alteration.—Throughout the mine area, except in the sericitized borders of quartz-pyrite veins, the quartz monzonite looks almost fresh. The main alteration noticeable in hand specimens is in the plagioclase which has a chalky appearance and rarely shows any twinning striations. Some of the biotite also is altered to a soft, buff-colored micaceous mineral either in the form of pseudomorphs or aggregates. However, the rock, generally, has retained its original color and texture. Under the microscope the plagioclase is seen to be largely replaced by clay minerals. Because of this it slakes quickly in water and the broken rock in the mine crumbles rapidly during rainy weather. In some places the plagioclase is stained a light brown color probably by included limonite in the clay, and when it is moist, it commonly has a pale greenish color due to adsorbed copper sulphate.

The minerals of the quartz monzonite have been selectively attacked in the course of the clay alteration. Quartz and orthoclase were stable except in a few places where the alteration is most intense, and a few tiny veinlets and small patches of clay replace both minerals. Biotite was relatively stable but was bleached and partly replaced by clay where the alteration was severe. Plagioclase was the least stable of the original minerals, and in many places where the biotite remains nearly fresh the plagioclase has been completely re-

placed by clay. Sphene and ilmenite were converted to leucoxene or fine grained rutile, and most of the apatite has been destroyed.

Variations in the intensity of the clay alteration in the mine are rarely evident except under the microscope. The study of thin sections clearly shows that the amount of clay varies from place to place but no systematic arrangement of these variations has been recognized. The alteration was probably more severe along some of the larger fractures, but every part of the rock within the clay zone was affected to some degree. This is in marked contrast to the localization of quartz-sericite alteration along veins which cut both the argillized and propylitized zones. The only systematic variation observed in the general clay alteration is a decrease in the amount of clay minerals both north and south of the mine area.

The zones of clay and propylitic alteration overlap as an ill defined zone where both are represented. In this zone of overlap, which is best developed north of Porphyry Mountain, clay occurs in plagioclase together with scattered sericite and a little clinozoisite, epidote, and chlorite; biotite is partly replaced by chlorite and epidote but mostly is unaltered. Much of the original sphene is converted to leucoxene, but apatite is fresh. The propylitic alteration of the marginal zone is undoubtedly a feebler phase of alteration than the clay phase. The overlap might suggest that clay alteration encroached on propylitic alteration. However, in the mine, which is entirely within the clay zone, nothing indicates that the rocks were propylitized before the clay alteration occurred. Fresh original biotite is common, and even slight replacement of it, or of plagioclase, by chlorite is decidedly rare. No epidote or carbonates have been found in the mine. However, scattered fine sericite which is not apparently related to veins occurs in the plagioclase throughout the mine and probably developed ahead of the clay alteration.

The dominant clay mineral is a colorless or slightly yellowish montmorillonite-type clay which has been tested by C. S. Ross [5] of the Geological Survey by means of differential heating methods. He reports:

"This shows that the material gives a typical montmorillonite curve, and also shows very clearly that the exchangeable base is calcium."

J. M. Axelrod of the Geological Survey made an x-ray analysis of the argillized plagioclase and found that it contains a member of the montmorillonite group, muscovite and a very little plagioclase. The clay mineral has a refractive index for beta of 1.545 and a birefringence of 0.02 +. It is tentatively called beidellite because it corresponds approximately to beidellite described by Lovering [6] in the altered rocks bordering tungsten veins in Boulder County, Colorado. Examination of the argillized plagioclase by immersion methods reveals minor amounts of another clay mineral whose refractive index is near 1.52 and a very small amount of an isotropic mineral of low refractive index which is probably allophane.

Beidellite occurs alone in veinlets, as very fine aggregates, and as scattered larger flakes. It is generally associated with some sericite and a micaceous

[5] Ross, C. S., personal communication.

[6] Lovering, T. S., The origin of the tungsten ores of Boulder County, Colorado. ECON. GEOL. 36: 229–279, 1941.

mineral having indices of refraction between those of beidellite and sericite, which is undoubtedly hydrous mica. Hydrous mica cannot be distinguished from muscovite by means of x-ray patterns.

Under the microscope the replacement of plagioclase by clay can be seen in various stages of completion. Where incomplete, irregular patches and replacement veinlets of the clay mixture occur in the plagioclase apparently uncontrolled by the crystal structure of the plagioclase. Though the clay mixture may replace any part of the original plagioclase grains, it commonly has replaced the central part leaving a less altered rim where replacement is less complete. In some parts of the mine the original plagioclase has been entirely replaced, and where this has happened orthoclase and biotite have also commonly been partly replaced by clay minerals, indicating a local area of more intense clay alteration.

Nearly everywhere small blades and veinlets of sericite are scattered through both plagioclase and the clay that replaced it. Whether the sericite occurs in the plagioclase or in the clay it is generally oriented in two directions, one parallel to the twinning striations of the plagioclase and the other approximately at right angles to them. Where replacement of the plagioclase by clay is not complete, there is less sericite in the clay than in the remaining plagioclase; and where the replacement is complete sericite is less abundant or even absent. This observation by itself might indicate either that sericite replaced plagioclase more readily than clay, or that clay has replaced sericite developed in the plagioclase ahead of the clay alteration. Because the sericite in the clay has the same orientation that it has in the plagioclase, it seems likely that this sericite formed early and was later partly replaced by clay. Indeed some sericite flakes scattered through the clay are ragged as though slightly replaced; and in some partly altered plagioclase, tiny sericite veinlets along twinning planes (010) continue from the fresh plagioclase into the clay as ragged trains of sericite flakes. A few plagioclase crystals completely replaced by clay contain some large flakes of beidellite scattered through a very fine-grained clay matrix. Many of the beidellite flakes are oriented and some occur in parallel stringers suggesting perhaps that the early sericite in the plagioclase has been pseudomorphed by beidellite.

A very few grains of blue tourmaline occur here and there in the argillized plagioclase.

Much of the biotite in the clay zone is unaltered but in areas of relatively intense clay alteration it is commonly bleached. The area of most general bleaching is in the west central part of the mine suggesting stronger clay alteration there than elsewhere. The original brown biotite is converted to a colorless or buff-colored mineral of micaceous habit that generally pseudomorphs the original biotite. The mineral looks much like sericite in hand specimens but is softer. Where the bleaching is incomplete, fresh biotite grades into the bleached product. The mineral has a variable but generally low birefringence and refractive index that varies but has a minimum value of about 1.550; it is biaxial, having a negative sign and an optic axial angle (2V) that is small but variable. The bleaching process is probably a simple leaching of the bases from biotite without noticeable recrystallization and the ultimate

product appears similar to kaolinite. In some places beidellite replaces both fresh and bleached biotite.

In the clay zone, sphene and ilmenite, which are generally associated with biotite in the fresh rock, are recrystallized to leucoxene or fine grained rutile. The outlines of euhedral sphene crystals are commonly preserved by the rutile aggregates. Where biotite is altered the rutile inclusions originally present in it have also been recrystallized to tiny granules.

Apatite also is generally associated with biotite in the fresh rock and is most abundant as inclusions in the biotite. In the clay zone it is rare or absent. Where fresh biotite remains, cavities having the shape of apatite crystals indicate that apatite was originally present; but only a few grains, which are commonly corroded, remain.

All of the plagioclase in the diabase sills in the mine has been replaced by clay. Although the composition of the original plagioclase in these sills is unknown, it was undoubtedly more calcic than the oligoclase in the quartz monzonite. Some of the green biotite in the sills has been bleached and partly replaced by clay, and a few veinlets of clay cut the sparse quartz grains that are generally present in the diabase. Leucoxene, developed by the alteration of ilmenite, is abundant. In addition to the clay replacing the minerals of the diabase, thin veinlets of beidellite occur along many of the fractures in the brecciated sills. The rock usually breaks along these seams, and the fragments are coated with the white clay.

Quartz-Sericite Alteration.—Each quartz-pyrite vein is bordered by a narrow zone of alteration where the rock is replaced by sericite and quartz with a little pyrite and adularia. Along tiny veinlets the alteration extends only a fraction of an inch into the wall rock; but along larger veins and particularly where pyrite is abundant, the sericitized borders are commonly several inches wide. Within these glistening white border zones the original texture of the rock is either obscure or completely destroyed. The general effect is that of a layer of intense alteration separating each vein from rock of more normal appearance; and because the veins are numerous and generally parallel, the alteration borders along them appear as thin white stripes cutting through rock in which the original color and texture are generally preserved. In a few small areas in the mine, particularly north of the ore body where veins are large and most numerous, the alteration borders along the veins coalesce, and the rock is completely replaced by sericite and quartz. The outer margin of the quartz-sericite alteration along veins is not abrupt, though in hand specimens it commonly appears to be. Sericitization persists farthest from the veins in those original minerals that are most susceptible to alteration. Close to the veins, plagioclase and clay are completely replaced by sericite; orthoclase and biotite are replaced by both quartz and sericite; and original quartz is partly replaced by sericite. Rutile and zircon are the only minerals not attacked. Beyond a certain limit original quartz and orthoclase are essentially unaltered, but sericitization of plagioclase and clay and of some biotite persists farther from the vein. Thus plagioclase and clay are most susceptible to alteration, and biotite is more stable but breaks down more readily than quartz or orthoclase. Apatite is rare having been largely leached during the clay

phase of alteration. What commonly appears in hand specimens to be a sharp outer limit of the sericitized border along a vein is simply that limit where orthoclase ceases to be sericitized and a change in the general color of the rock occurs because of the contrast between the fresh reddish orthoclase and the glistening white sericite.

Relatively little quartz-sericite alteration occurs along veins without pyrite or veins containing only a little pyrite associated with other sulphides. In a single small area, quartz-pyrite veins bordered by pronounced zones of alteration may be present along with other veins containing barren quartz, or chalcopyrite or molybdenite with quartz, that cut sharply through what appears to be unsericitized rock. Indeed some chalcopyrite veinlets cut through large orthoclase phenocrysts without producing noticeable alteration. Microscopic study, however, generally reveals a little sericitization of the wall rock along chalcopyrite and molybdenite-bearing veins; and feldspars cut by these veins may be slightly replaced by quartz. However, none of the original minerals is completely replaced and in hand specimens the alteration is not evident. Pyrite-free veins do occur close to or actually intersect quartz-pyrite veins and therefore occur in the alteration zones along pyrite veins, but all positive evidence indicates that intense quartz-sericite alteration is related to the quartz-pyrite veins and that only minor silicification and sericitization accompanied the chalcopyrite and molybdenite phases of the mineralization.

Veins containing adularia can rarely be recognized in the field, but thin sections show that a small amount of adularia is common in veins containing chalcopyrite or molybdenite. Adularia also occurs in the walls of the quartz-pyrite veins, but none has been seen in these veins with the exception of a single specimen in which adularia crystals occupy a vug in a quartz-pyrite vein. Only a little adularia penetrates the wall rock as a replacement mineral and where it does it is invariably associated with sericite. In specimens containing the most adularia sericite blades and rosettes replacing quartz commonly are separated from the quartz by thin selvages of adularia, and stringers cutting through the quartz contain sericite in the center and adularia along the margins. Probably sericite first replaced quartz and later selective replacement of sericite by adularia occurred along the quartz-sericite boundaries. This relationship occurs in some vein quartz as well as in original quartz grains, and together with the apparent association of adularia with chalcopyrite and molybdenite, it suggests that adularia was formed during the later stages of sulphide mineralization and quartz-sericite alteration.

Not only were some of the original minerals more susceptible than others to the quartz-sericite alteration, but the character of the alteration in the various minerals is distinctive. Quartz close to the veins has been partly replaced by coarse blades and rosettes of sericite. Also in orthoclase, the sericite occurs as coarse blades, but the blades are generally oriented along planes approximately at right angles as if controlled by the orthoclase structure, and invariably some silicification of the feldspar has taken place. In contrast, plagioclase and clay near quartz-pyrite veins have been replaced by extremely fine-grained sericite without any replacement by quartz. The original plagioclase can generally be recognized in completely altered rocks along the veins by mi-

crocrystalline aggregates of sericite having the shape of feldspar grains. The probable explanation for the lack of silicification in plagioclase is that both plagioclase and the clay developed in it are very susceptible to sericitization and were rapidly and completely replaced by sericite at the beginning of the quartz-sericite phase of alteration. The plagioclase having been sericitized, replacement by quartz was probably prevented. There is no definite evidence that quartz has replaced sericite anywhere in the Castle Dome area.

Biotite has been replaced by both sericite and quartz in the alteration borders along quartz-pyrite veins. The product is a pseudomorph composed of coarse sericite and quartz containing small aggregates of rutile. In some specimens the place of original biotite is indicated only by these rutile aggregates.

Rutile and leucoxene, developed from original sphene during the clay alteration, have likewise been recrystallized in the quartz-sericite borders along the veins to aggregates of larger grains. Commonly these aggregates also contain quartz and a few of them preserve the outlines of original euhedral sphene.

Quartz-pyrite veins in the diabase sills, as in the quartz monzonite, are bordered by zones of intense quartz-sericite alteration.

Areal Distribution of Alteration Phases.—Alteration and mineralization are almost confined to the quartz monzonite and the granite porphyry intruded into it. Figure 4 shows a generalized arrangement of the alteration phases into several zones. These zones are not concentric but rather extend across the quartz monzonite as bands trending in an east-northeast direction. The boundaries between them are gradational in a north-south direction. To the east, west, and south the alteration either ends at the margins of the quartz monzonite or is very weak beyond them, whereas to the north in the quartz monzonite the alteration decreases gradually until it becomes unrecognizable in the field.

The quartz-sericite phase of alteration is not confined within any well defined zone but occurs throughout the mineralized area along pyrite veins and veinlets cutting through both argillized and propylitized rock. However, a central area where pyrite mineralization and the associated quartz-sericite alteration are most intense can be clearly recognized. This is a zone passing through the summit of Porphyry Mountain and extending eastward nearly to the edge of the quartz monzonite and westward to the Gold Gulch fault (Fig. 4). The amount of pyrite and quartz-sericite alteration decreases gradually both to the north and to the south. Therefore, any northern or southern limit of this central zone is arbitrary and depends on the criteria chosen to define it. Because local intense sericitization and silicification occur along many faults, it is difficult to outline a single zone within which intense quartz-sericite alteration is confined, but examination in the field leaves no doubt that as Porphyry Mountain is approached either from the north or south the average intensity of quartz-sericite alteration increases greatly. Reasonably definite outlines of the central zone can be described only if the zone is defined as that area containing the greatest concentration of pyrite and the largest and most numerous quartz-pyrite veins as well as the greatest average intensity of quartz-sericite alteration. Thus defined, the central zone of generally strong quartz-sericite

STATE COLLEGE OF AGRICULTURE AND APPLIED SCIENCE
LIBRARY
JAN 9 1947
KANSAS

alteration is arbitrarily made to correspond with the pyrite zone in hypogene mineralization. Its southern boundary is in the footwall of the ore body, its northern boundary is beneath the dump. To the east and west it ends abruptly near the margins of the quartz monzonite.

The most intense quartz-sericite alteration is entirely within the area where strong clay alteration occurs. Indeed, clay alteration can be seen within the central zone wherever the quartz monzonite is not completely sericitized and silicified. To the south, and probably beneath the dump to the north, quartz-pyrite veins are fewer and smaller, quartz-sericite alteration is generally less, and clay is the dominant alteration product. Farther from Porphyry Mountain the amount of clay as well as quartz-sericite alteration decreases, and in the marginal parts of the mineralized area to the north small veins with thin borders of quartz-sericite alteration occur in the propylitized rock containing no clay. Clearly the veins and the quartz-sericite alteration are imposed on the slightly earlier clay and propylitic phases of alteration, but all are apparently zoned about a center on Porphyry Mountain and undoubtedly all are stages in a single mineralization process.

A second smaller center of intense quartz-sericite alteration is on the south side of South Hill (Fig. 4). Strong alteration comparable to that in the mine area extends well down the north slope of the hill. It is separated from the strongly altered area on Porphyry Mountain by relatively weak clay and propylitic alteration which is associated with seemingly weak pyrite-chalcopyrite mineralization, whereas on South Hill copper mineralization is relatively strong as shown by three exploratory drill holes.

Faults controlled the variations in quartz-sericite alteration in many parts of the mineralized area. The intense alteration on South Hill (Fig. 4) was undoubtedly controlled by the fault zone separating the Pinal schist from quartz monzonite on the south side of the hill. The fault itself is mineralized and alteration decreases northward away from it. West of the mine, the Gold Gulch fault is the western boundary of strong alteration and mineralization, although the fault itself is mineralized and altered. West of it both alteration and mineralization are very weak. To the north, the East Branch of the Gold Gulch fault is the western boundary of the area in which mineralization and quartz-sericite alteration are pronounced, and the alteration extends farthest northward along this fault as well as along the group of north-northwest trending faults a few hundred feet to the east. Intense quartz-sericite alteration also occurs along the northeast-trending fault about 500 feet northwest of the Continental mine, and local intense sericitization is evident along the Dome fault in the southwestern part of Castle Dome mine and along many minor faults elsewhere in the mine. Probably many of these same faults also influenced the distribution of both clay and propylitic alteration but there is no direct indication that this is so.

Recrystallization of Biotite.—The original biotite that characterizes the quartz monzonite occurs as dark brown subhedral books, but within and south of the Castle Dome mine much of the original biotite is recrystallized to aggregates of small biotite plates, a few of which are intergrown with muscovite. Biotite aggregates are about the same size as the books ($\frac{1}{10}$ to $\frac{1}{4}$ inch in di-

ameter), and they have about the same distribution in the rock. Invariably they are associated with small crystals of apatite, ilmenite, and sphene as are the books. In thin sections, various stages in the change from book to aggregate biotite can be observed. Such aggregates have a core composed of a remnant of the original book surrounded by numerous small biotite crystals having various orientations, and others are completely recrystallized. From a few biotite aggregates as centers, small trains of tiny biotite crystals extend as much as 1/10 inch into the surrounding quartz and feldspars. In the quartz monzonite near some of its contacts with granite porphyry south of the mine aggregates of biotite can be seen, but fine grained biotite is scattered throughout the rock in veinlets that cut through all of the other minerals.

The composition of the biotite in books and in aggregates may vary slightly, but the optical properties of the two are essentially the same. Most of the original books contain needlelike rutile inclusions oriented in three directions at 60° in the basal plane (001). These inclusions have not been noted in the aggregate biotite seen in thin sections.

Aggregate biotite does not occur north of the mine and it increases in abundance toward the south. Near Gold Gulch and on South Hill biotite occurs only in the form of aggregates, although the biotite in the granodiorite and granite porphyry in that area occurs as thin plates and probably none has recrystallized.

The cause of the recrystallization of biotite is uncertain. At first it was thought that the recrystallization was an effect of hydrothermal alteration related to the copper mineralization and a record of its distribution was kept during the study of alteration in the mine. However, the distribution of aggregate biotite, showing the greatest recrystallization near the southern margin of the quartz monzonite, does not appear to conform to the zoning in the hypogene copper mineralization or the associated hydrothermal alteration although it does occur entirely within the mineralized area. Furthermore both types of biotite have been affected by propylitic, clay, and quartz-sericite phases of the alteration. Perhaps the recrystallization is a metamorphic effect produced by the intrusion of granite porphyry near the south margin of the quartz monzonite, or if the root of the quartz monzonite instrusion is south of Porphyry Mountain, as is likely, the recrystallization of biotite may be a deuteric change. S. G. Lasky [7] reports that in the Little Hatchet Mountains of New Mexico he found that such recrystallized biotite was a metamorphic effect, both endomorphic and exomorphic.

Supergene Clay Minerals.—Several clay minerals that appear to be of supergene origin are present in small amounts in the capping and in the chalcocite zone. These include halloysite, endellite, cimolite, and probably kaolinite. Halloysite, endellite and cimolite occur in small masses filling open fractures. They have been transported into cavities and clearly did not form by replacement of rock minerals. Some kaolinite is a product of weathering in the unmineralized quartz monzonite.

Chemical and Mineralogical Changes.—Chemical analyses of the fresh and altered quartz monzonite are shown in Table I. The samples representing

[7] Unpublished manuscript, U. S. Geol. Survey.

TABLE I.

CHEMICAL ANALYSES OF THE FRESH AND ALTERED QUARTZ MONZONITE.

Norman Davidson, Analyst.

Sample No.	1 Fresh	2 Fresh	3 Alt.	4 Alt.	5 Alt.
SiO_2	69.60	70.68	69.20	70.33	72.15
Al_2O_3	13.99	13.82	14.33	14.53	11.77
Fe_2O_3	1.82	2.03	1.03	.50	1.00
FeO	2.15	1.83	.99	1.03	.96
MgO	.86	.44	.73	.59	.43
CaO	2.12	1.61	.25	.32	.23
Na_2O	2.66	2.64	.72	1.02	.28
K_2O	4.56	4.48	5.53	6.10	3.46
H_2O − 110° C.	.14	.14	1.75	1.08	.02
H_2O + 110° C.	1.00	1.26	2.81	1.76	1.82
TiO_2	.62	.55	.66	.51	.43
P_2O_5	.23	.19	.13	.13	.08
MnO	.13	.11	.01	.02	.01
FeS_2	.02	.05	1.72	1.76	7.05
	99.90	99.83	99.86	99.68	99.69
Sp. gr. (bulk)	2.7	2.6	2.3	2.3	2.8
Sp. gr. (powder)	2.88	2.74	2.69	2.60	2.99

1 and 2. Unaltered quartz monzonite porphyry. ½ mile due north of Porphyry Mountain.
3. Altered quartz monzonite porphyry, clay phase.
4. Altered quartz monzonite porphyry, clay-sericite phase.
5. Altered quartz monzonite porphyry, quartz-sericite phase.

the fresh and altered rocks were necessarily collected from widely separated areas. Samples 1 and 2, representing fresh rock, were collected north of the dump about one-half mile from the area in the mine where the altered samples were taken. Although both samples appeared fresh, microscopic examination showed slight weathering of the plagioclase and the presence of some minerals of the propylitic phase. In order to appraise the accuracy of the sampling, two samples of the fresh rock, judged by inspection to be as similar in composition and texture as possible, were collected about 500 feet apart. To insure accurate sampling of such a coarse-grained rock, large samples were cut. These were crushed and reduced to convenient-sized pulps for chemical analysis by approved sampling methods.

The two analyses agree very well in those oxides which represent the essential constitutents of the rock. The differences between the two are believed to represent actual differences in composition rather than errors in sampling and analysis. In the tables that follow an average of the two analyses is used to represent the composition of the fresh rock.

Table II is an attempt to recast the analyses to show the approximate mineral composition of the fresh and altered rocks. Although in detail the computed mineral composition is not strictly accurate, the major constituents conform with the general mineral composition observed during the study of about 125 thin sections. The boldest assumption involved in the construction of the table is that the original composition of all the samples before alteration was

TABLE II.

RECAST OF THE CHEMICAL ANALYSES TO SHOW APPROXIMATE MINERAL COMPOSITION OF THE FRESH AND ALTERED QUARTZ MONZONITE.

Sample No.	1 and 2 Fresh	3 Alt.	4 Alt.	5 Alt.
Quartz	32.66	35.03	36.23	57.10
Orthoclase	22.29	25.68 [b]	25.68 [b]	—
Albite	22.55	6.09	8.69	2.38
Anorthite	7.03	.49	.85	—
Biotite	7.27	—	—	—
Apatite	.50	.28	.28	.17
Ilmenite	.61	—	—	—
Sphene	.63	—	—	—
Magnetite	2.67	—	—	—
Kaolinite	3.01 [a]	—	—	—
Bleached biotite	—	3.83	3.08	—
Rutile	—	.66	.51	.43
Beidellite	—	16.92	8.70	.21
Sericite	—	6.35 [c]	11.86 [c]	29.33
Limonite	—	1.26	.61	1.23
Pyrite	.03	1.72	1.76	7.05

[a] Excess alumina computed as kaolinite, includes minor amounts of other alteration minerals.
[b] Orthoclase assumed to remain unaltered in these phases. Percentage was computed on basis of equal weights in equivalent volumes of the fresh and altered rocks. (See Table IV.)
[c] Hydrous mica computed as sericite.

the same. This is obviously only approximately true. Some very minor constituents were ignored, and the exact composition of many of the alteration products is uncertain. For example, the nature of the chemical changes in the bleaching of biotite is not known, nor is the degree of base exchange in the clays. The amount of orthoclase in samples 3 and 4 is based on the assumption that in these phases all the orthoclase remains unaltered, that is, the weight of orthoclase in equivalent volumes of the fresh and argillized rock is the same

TABLE III.

SHOWING THE WEIGHT IN GRAMS OF EACH OXIDE IN 1 CUBIC CENTIMETER OF THE FRESH AND ALTERED QUARTZ MONZONITE.

Sample No.	1 and 2 Fresh	3 Alt.	4 Alt.	5 Alt.
SiO_2	1.858	1.592	1.617	2.020
Al_2O_3	.368	.329	.334	.330
Fe_2O_3	.051	.024	.012	.028
FeO	.053	.023	.024	.027
MgO	.017	.017	.014	.012
CaO	.050	.006	.007	.006
Na_2O	.071	.017	.023	.008
K_2O	.119	.127	.140	.097
H_2O −110°	.004	.040	.025	.001
H_2O +110°	.030	.065	.041	.051
TiO_2	.016	.015	.012	.012
P_2O_5	.006	.003	.003	.002
MnO	.003	—	—	—
FeS_2	.001	.040	.041	.197

(see Table IV). The study of thin sections shows ample evidence to justify this assumption.

The gains and losses of the constituents in equivalent volumes of the fresh and altered rocks can be seen in Table III, which shows the computed weights of the various constituents in one cubic centimeter of rock. Although the values for samples 3 and 4 are not entirely accurate because of the difficulties encountered in determining the bulk specific gravities of these highly argillized rocks, they are considered sufficiently reliable to illustrate the general changes in composition.

Table IV shows the weights of the mineral constituents in one cubic centimeter of rock. In studying the chemical and mineralogical changes illustrated by these two tables the reader should realize that the relationships between the samples are not necessarily one of progressive change from fresh quartz monzonite through an argillized phase, as represented by No. 3, and an intermediate phase, represented by No. 4, to a rock almost completely replaced by quartz and sericite. The intermediate sample (No. 4) was probably never as completely argillized as No. 3; and the higher plagioclase content should not be construed to indicate that plagioclase has been introduced, but rather that the plagioclase in this sample is not as completely altered as that in No. 3.

In the alteration of the fresh rock to the clay phase, only plagioclase and biotite suffered noteworthy change. The decrease in silica (Table III) represents an actual leaching accompanying the replacement of oligoclase by clay. Quartz (Table IV) decreases slightly; but since microscopic study shows that quartz is rarely replaced in the clay phase, the decrease shown by sample 3 may be at least partly due to a primary difference in composition. Magnesia remains constant, whereas lime, soda and alumina decrease due to the de-

TABLE IV.

SHOWING THE WEIGHT IN GRAMS OF EACH MINERAL CONSTITUENT IN 1 CUBIC CENTIMETER OF THE FRESH AND ALTERED QUARTZ MONZONITE.

Sample No.	1 and 2 Fresh	3 Alt.	4 Alt.	5 Alt.
Quartz	.865	.806	.833	1.599
Orthoclase	.591	.591 [a]	.591 [a]	—
Albite	.597	.140	.200	.067
Anorthite	.186	.011	.019	—
Biotite	.192	—	—	—
Apatite	.013	.006	.006	.005
Ilmenite	.016	—	—	—
Sphene	.017	—	—	—
Magnetite	.070	—	—	—
Kaolinite	.080	—	—	—
Bleached biotite	—	.088	.071	—
Rutile	—	.015	.012	.012
Beidellite	—	.389	.200	.006
Sericite	—	.146 [b]	.273 [b]	.821
Limonite	—	.029	.015	.034
Pyrite	.001	.040	.041	.197

[a] All orthoclase assumed to remain unaltered in these phases.
[b] Hydrous mica computed as sericite.

struction of plagioclase. Both ferric and ferrous iron are leached. Potash is added and appears as sericite and hydrous mica associated with the clay. It is highest in sample 4 in which the plagioclase contains a higher ratio of sericite to clay. Total water reaches a maximum in the most highly argillized rock and decreases as the proportion of sericite to clay increases. Titanium oxide remains virtually constant in the change from primary ilmenite and sphene to rutile and leucoxene in the altered rock. About half of the apatite is leached at this stage of alteration. The residual plagioclase becomes progressively more sodic as the degree of alteration increases.

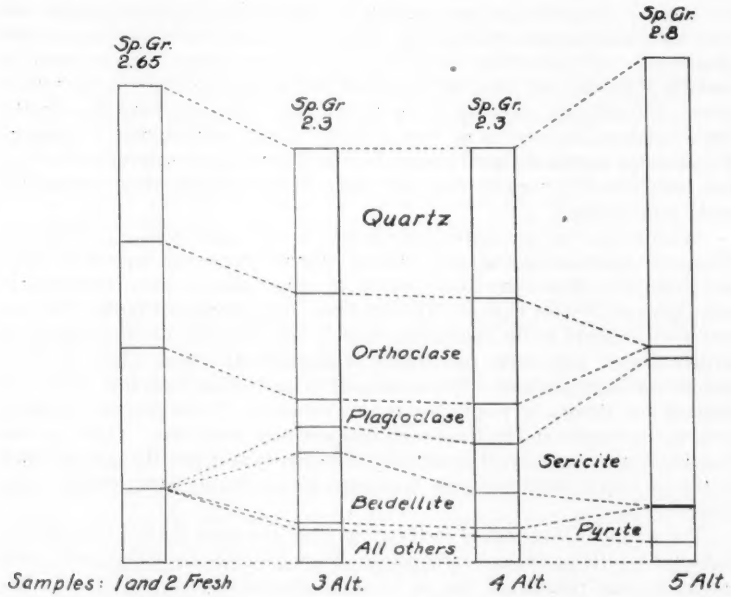


FIG. 5. Diagram showing mineralogic changes in the alteration of 1 cubic centimeter of quartz monzonite.

In the final stage of quartz-sericite alteration, represented by sample 5, all the original minerals of the rock are destroyed except quartz which suffers only a minor degree of replacement by sericite. Silica increases mainly by the introduction of vein quartz. Alumina remains nearly constant after the plagioclase is destroyed. Water expelled below 110° C. decreases to a minimum with complete substitution of clay by quartz and sericite. Potash decreases when orthoclase is replaced, but even after complete replacement it is only a little lower than in the fresh rock. The relatively high ferric iron content of the altered rocks, especially in the quartz-sericite phase, is due to supergene products, mainly limonite, resulting from the oxidation of pyrite. Sample 5

contains a small excess of lime, magnesia and ferrous iron which is not accounted for by any mineral recognized in thin sections of the rock. The changes in mineral composition from fresh quartz monzonite to the altered phases in equivalent volumes of rock are illustrated in Fig. 5.

CHARACTER OF THE MINERALIZING SOLUTIONS.

What little can be said concerning the character of the mineralizing solutions must be inferred from the effects which the solutions produced in the rocks within the present range of observation, approximately 900 feet in vertical extent. The solutions apparently were rich in silica, iron and sulphur and also contained copper, molybdenum, zinc, lead, barium and probably a little phosphoric acid and carbon dioxide. Most of the sulphur was deposited as metallic sulphides, but some barite formed during the late stages of mineralization. The minerals produced in the altered host rock are among those generally considered to form in at least a mildly alkalic environment. Although the solutions may be assumed to have been acid nearer their source, no evidence has been found to suggest that they were still acid when they reached the rocks now exposed.

Whether or not they carried potash from their magma source is debatable. Along the veins and in the most intensely altered parts they deposited quartz and pyrite and altered the rock minerals to quartz and sericite. Here potash was removed to some extent. The solutions, that penetrated farther into the wall rock adjacent to the veins and probably also the rock above the most intensely altered zone, were so changed in character that their ability to form sericite was largely spent. They continued to leach soda, lime, iron, silica and alumina and altered the plagioclase to clay minerals. Some potash was added to form the sericite and hydrous mica disseminated in the clay. If we assume that silicification and sericitization are more intense at depth, the potash added in the clay zone could easily be accounted for as having been leached from deeper rocks.

The solutions that soaked farthest out from the main paths of circulation deposited a little pyrite and carbonates. They may also have deposited some magnesia, lime, potash and iron to form the alteration minerals characteristic of the propylitic zone; at least they were sufficiently concentrated in these bases to prevent further leaching.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.,
Oct. 25, 1946.

CLARKSBURG KAOLIN AREA OF CARROLL COUNTY, TENNESSEE.[1]

BY GEORGE I. WHITLATCH AND BENJAMIN GILDERSLEEVE.

ABSTRACT.

Drill-prospecting by the Tennessee Valley Authority in 1941 near Clarksburg, Carroll County, Tennessee, disclosed a kaolin zone and associated series of sediments which are correlated with the Ackerman formation, the lowermost member of the Wilcox group (Eocene) of Mississippi. This formation, heretofore, has been considered to be absent on the outcrop in Tennessee, although the senior author had previously suggested its probable occurrence on the basis of stratigraphic and lithologic evidence.

Certain features of the kaolin-bearing zone in the Clarksburg area are suggestive of deposition within a basin-like depression, and all evidence—both outcrop and drilling—indicates a sedimentary origin for the kaolin and associated sediments. The original source of the kaolin is believed to be the Porters Creek clay. It is suggested that, in the long Midway-Wilcox interval, the old Midway surface was deeply leached and ultimately developed a more or less continuous mantle of residual kaolin. In early Ackerman time, regional uplift and rejuvenation of erosive forces is believed to have swept these kaolins from the old Midway surface and deposited them in lagoons bordering the Ackerman sea.

The drill-prospecting indicated 4,749,000 tons of minable clay which had a weighted Al_2O_3 content of 34.3 per cent and a weighted Fe_2O_3 content of 1.1 per cent.

INTRODUCTION.

THE precarious dependency of the American aluminum industry on imported bauxite ores during war time stimulated the development of practical processes for extraction of alumina from kaolin, alunite, and other aluminous materials. Prominent among the alumina-from-clay processes is the Walthall process announced in 1940 by the Tennessee Valley Authority, Department of Chemical Engineering.

The TVA, as a consequence of its experimental alumina-from-clay researches, began a reconnaissance of the Tennessee Valley region as early as 1938 to locate potential sources of high-alumina clays (minimum Al_2O_3 content of 32 per cent and maximum Fe_2O_3 content of 2 per cent) suitably situated to supply an alumina plant of 150-ton daily capacity. Five promising localities were found in the Valley, one each in Alabama, Georgia, and Mississippi, and two in Tennessee. The present paper describes the results of intensive explorations made in West Tennessee by the TVA in co-operation with the Tennessee Department of Conservation, Division of Geology. Selection of this region was due to the large body of data available from previous studies by

[1] A complete report on the kaolins of West Tennessee will be published in the future by the Tennessee Division of Geology.

the TVA and the Tennessee Division of Geology on the ball clays, long mined here for the ceramic trades, and to more recent discovery of sedimentary kaolin deposits.

The clay body most extensively prospected is a sedimentary kaolin deposit near Clarksburg, about 10 miles south of Huntingdon, Carroll County, Tennessee. This locality is, therefore, called the Clarksburg kaolin area.

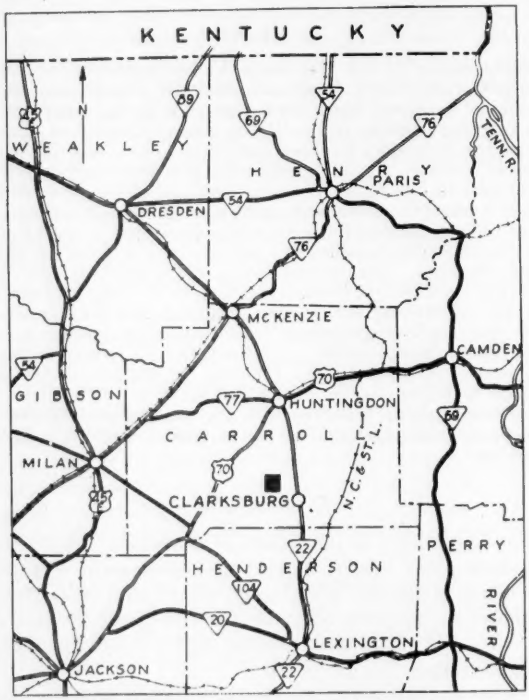


FIG. 1. Location of Clarksburg Area in West Tennessee.

GENERAL STRATIGRAPHY.

The Clarksburg kaolin area, geologically, is in the "Gulf Embayment," a broad structural basin filled with essentially unconsolidated sediments of the Cretaceous, Tertiary, and Quaternary systems. Only Tertiary formations of the Wilcox and Midway groups were directly involved in the present investigations.

The Tertiary formations, with the exception of the Clayton, crop out from east to west in successive belts of varying widths that extend north-south across the entire State and roughly parallel the strike of the Cretaceous formations to

the east. North of Hardeman County the Clayton is overlapped by the Porters Creek. On the west, the Grenada is overlapped and disappears beneath the Pleistocene loess that mantles the westernmost third of the region. The aggregate width of these formations is about 50 miles along the Mississippi state line, but narrows to about 40 miles at the north along the Kentucky line.

The Clayton, Grenada, and Jackson formations are without significance in the Clarksburg kaolin area; consequently, details concerning their distribution and general character are omitted from this discussion.

Porters Creek Formation.—The Porters Creek formation immediately overlies the Clayton formation in Hardeman County, but north of there, the latter formation apparently is overlapped and the Porters Creek rests unconformably on the Cretaceous (Ripley formation). The outcrop belt of the

GENERALIZED SECTION OF EOCENE FORMATIONS OF WEST TENNESSEE

	Formation	Columnar Section	Thickness (in feet)	Physical Character
	Jackson formation		100 to 200 ±	Grayish thin-bedded fine sands with interbedded lenses of clay and lignite.
Wilcox group	Grenada formation		600	Variegated sands with interbedded lenses of clay and clayey lignites. Similar lithically, although the Grenada sands are generally finer-grained. Best identified by flora
	Holly Springs formation		to	
	Ackerman formation		1900 ±	Alternating series of kaolins, lignitic sands, silts, and sandy clays. Locally contains limonite concretions, clay pellets, and "sawdust" sands.
Midway group	Porters Creek Clay		95 to 360 +	Dove-gray to black massive joint-clay, distinct conchoidal fracture. Thin micaceous and glauconitic sandy phases.
	Clayton formation		0 to 121 ±	Glauconitic sands, clays and indurated sand layers with a thin-bedded limestone near base.

FIG. 2.

Porters Creek formation is one to eight miles wide and extends south-southwest across the State through Henry, Carroll, Madison, Henderson, Chester, and Hardeman counties. The formation is well exposed in all of these counties. The greatest known outcrop thickness of the formation exceeds 90 feet, at "Pinson Hill" in Madison County; the known maximum subsurface thickness is 360 feet, recorded in logs of wells drilled in the vicinity of Memphis near the Gulf Embayment axis.

The greater part of the Porters Creek formation is composed of a dove-gray to dark lead-gray, massive, non-plastic joint clay of the montmorillonite type. The clay, when wet, is almost black and has a soapy feel, hence the local appellation of "soapstone." The dry clay is normally quite porous and appreciably lighter in weight than other types of clay. It weathers whitish or buff. Porters Creek outcrops have a distinctive hackly appearance, owing to develop-

ment in the clay of systems of vertical joints with attendant conchoidal fracturing of the clay blocks thus formed.

Although the Porters Creek clays are mostly rather massively bedded, the formation locally exhibits definitely shaly phases with a high percentage of interbedded fine-grained micaceous sand layers. Lenses of sand, ranging up to several feet in thickness, also occur locally, particularly in the upper part of the formation. Dikes of fine sand, varying from a few inches to as much as 22 feet in width, cut the formation in many localities, but they show no systematic orientation. Thin limonitic layers are common along some joints in the clay, and small nodules of iron carbonate occur erratically. At a few points near the base of the formation thin layers of lignite have been observed, but such occurrences are uncommon.

Ackerman Formation.—The Ackerman formation is recognized in the present report as the basal member of the Wilcox group of West Tennessee and as correlative, at least in part, with the Ackerman formation of Mississippi. This formation, heretofore, has been considered to be absent on the outcrop in Tennessee,[2] although Whitlatch [3] suggested its probable outcrop occurrence on the basis of stratigraphic and lithologic evidence, and Wells [4] previously had noted its presence as a subsurface formation.

Drill-prospecting of the kaolin-bearing zone in the Clarksburg area proved the presence of a thick alternating series of kaolins, lignitic sands and silts, sandy clays, and similar sediments immediately above the dark-gray clays and interbedded sands of the Porters Creek formation. Similar conditions have been noted in outcrops along State Road 20 near "Blue Goose" store, 1.9 miles east of the Henderson-Madison County line. Both the base and the top of this zone (kaolin and associated strata) are marked by unconformities which indicate that the sediments were deposited on a much eroded and very irregular Porters Creek surface and that they were also much eroded prior to deposition of the overlying Holly Springs formation. Locally, the Ackerman sediments have been completely removed by erosion, and the Holly Springs sands rest directly on indisputable Porters Creek clays.

The kaolin perhaps is the most distinctive feature of the Ackerman formation but, unfortunately, its outcrop occurrences are limited almost entirely to the Clarksburg area in Carroll County. The formation, on the whole, does not have any great uniformity over wide areas and locally exhibits rapid lateral changes from clayey sands or siltstones to silty clays that may be either shaly or massive. The kaolin zone in the Clarksburg area, however, is uniform and apparently persistent. Some of the silty clays are dark-gray and micaceous and are not readily distinguishable from those of the underlying Porters Creek formation. As a rule, the Ackerman clays have a fair plasticity whereas typical Porters Creek clay is relatively non-plastic.

[2] Roberts, J. K., and Collins, R. L., The Tertiary of West Tennessee. Am. Jour. Sci., 5th ser., vol. 12, 1926; Berry, E. W., Revision of the Lower Eocene Wilcox Flora of the Southeastern States. U. S. Geol. Surv. P. P. 165, 1930, p. 4.

[3] Whitlatch, G. I., The Porters Creek clay of Tennessee as a bleaching agent for oils. Oil and Soap, vol. 13, 1936, pp. 136–38; also The clays of West Tennessee. Tenn. Div. Geology Bull. 49, 1940, pp. 53–54.

[4] Wells, F. G., Ground water resources of Western Tennessee. Tenn. Div. Geology Bull. 44, 1933, p. 89.

Iron concretions, lignites, clay pellets, mica flakes, and "sawdust" sands are other lithologic features that are helpful, within certain limits, in the identification of the Ackerman formation, especially where the overlying basal Holly Springs sand can be identified. Large rounded concretions of very pure limonite are common at some localities in the Ackerman; these are oxidized siderite concretions, and similar unoxidized concretions were encountered frequently in drilling the kaolin-bearing strata in the Clarksburg area. "Pseudo bauxites" are present locally in the more basal parts of the Ackerman formation where zones or lenses of rounded clay pellets, resembling bauxite pisolites, occur embedded in a clayey fine-grained white or tan-colored sand matrix. This sand matrix, called "sawdust" sands by Whitlatch,[5] may locally be entirely free of pellets and form distinctive zones that are readily recognized but difficult of accurate description. These zones were formerly referred to the basal part of the Holly Springs formation.[6]

The maximum outcrop thickness of the Ackerman formation observed in the Clarksburg area of Carroll County was about 50 feet, but thicknesses in excess of 80 feet were recorded in the drilling done in this area.

No attempt has been made to map the outcrop belt of the Ackerman, but it probably is more or less discontinuous across the State, owing to local erosional absences of the sediments. The belt, where present, will occupy a relatively narrow strip along the presently mapped eastern edge of the Holly Springs formation.

Holly Springs Formation.—The Holly Springs formation is marked at its base by an erosional unconformity and, as a result, may rest either on the Ackerman formation of the Wilcox group or the Porters Creek formation of the Midway group. This formation, consisting predominantly of sands with interbedded clay lenses and associated clayey lignites, crops out across the State in a broad band that ranges from about 20 miles in width on the Mississippi line to about 8 miles at the Kentucky line. It is the surface formation of the western half of Carroll and Henry counties, most of Hardeman and Madison counties, and the southeast corners of Fayette, Haywood, Gibson, and Weakley counties. The formation thins northward from a 450-foot thickness in Fayette County to 250 feet in Henry County.

The sands of the Holly Springs formation are fine- to coarse-grained and, locally, gravelly. The extreme basal parts of the formation, particularly in the kaolin-bearing area of Carroll County, are marked by very coarse sands and by streaks and small lenses of quartz gravels. Colors of the sands are variegated, ranging from gray and brown through red, pink, purple and yellow to white, but orange-red and yellowish- to reddish-brown are most common. Strong cross-bedding of the sands is characteristic. Mica is usually present but not in extreme abundance. Clay conglomerates, composed of bodies ranging from well-rounded pellets or balls to only slightly rounded fragments, occur in association with local unconformities within the sands,

[5] Whitlatch, The Porters Creek clay of Tennessee as a bleaching agent for oils. Oil and Soap, vol. 13, 1936, p. 137.

[6] Roberts and Collins, op. cit.; Berry, E. W., op. cit.; Whitlatch, The clays of West Tennessee, op. cit.

the clay probably being redeposited from nearby outcrops. Similar conglomerates, as already noted, also occur in the basal parts of the Ackerman formation, and extreme care is necessary in field examination to determine the correct correlation.

The clays and associated clayey lignites of the Holly Springs constitute much less of the formation than do the sands. They occur within the sands as lenticular bodies that vary from only a few square feet to more than 50 acres in extent and from a few feet up to 80 feet or more in thickness. Their shapes vary from roughly circular to long and narrow with the long axis of the lens oriented north, slightly east, probably parallel to the old Wilcox coast line. These clays are the basis of the extensive clay mining industry in Henry and Carroll counties,[7] the lighter colored massive highly plastic types supplying the ball clays of commerce.

EXPLORATIONS.

Six tracts of land in the Clarksburg area were prospected by the TVA under agreements with the property owners during the period July 1–October 3, 1941.

In general, the area is characterized by a rolling topography of relatively low relief. Numerous small ridges and drainage divides interrupt the regional westward slope; gullies and ravines are common on hill slopes, locally forming a type of minature "badlands."

Intensive drilling on 200-foot centers was concentrated, for the most part, along the lower slopes of the dissected ridges. It was found that, below the 520-foot contour, the kaolin had been almost completely removed by recent erosion, and that above an elevation of 580 feet the overburden attained excessive thicknesses.

A total indicated 4,749,000 tons of minable kaolin was found which had a weighted Al_2O_3 content of 34.3 per cent, and a weighted Fe_2O_3 content of 1.1 per cent. Average thicknesses of minable kaolin in different parts of the area varied from 11.0 to 13.7 feet. Average thicknesses of overburden in different parts of the area varied from 9.9 to 39.5 feet. The average overburden-kaolin ratio for the entire area was 1.7 to 1, that is 1.7 cubic yards of overburden per ton of kaolin. No estimates were made for clay having an Al_2O_3 content less than 32.0 per cent and Fe_2O_3 content in excess of 2.0 per cent which were the specifications set by the TVA.

CLARKSBURG KAOLIN AREA.

Structure of the Kaolin Deposits.—All drill evidence obtained in the Clarksburg area confirmed outcrop observations that the kaolin zone and associated strata are separate from, and unconformably resting on, the underlying Porters Creek formation. This is an erosional unconformity, as noted previously by Berry.[8] Similar unconformable relations also were proved to mark

[7] Whitlatch, The clays of West Tennessee, op. cit.

[8] Berry, E. W., Lower Eocene floras of Southeastern North America. U. S. Geol. Surv. P. P. 91, 1916, pp. 73–78.

the Ackerman-Holly Springs contact, indicating that, prior to deposition of the Holly Springs sediments, the Ackerman was badly eroded.

Ackerman outcrops in this area commonly do not reveal either kaolin or other types of sediments, such as lignite, that can be considered indicative of a kaolin deposit. The occurrence here of this large body of kaolin and associated sediments seems due to a unique series of circumstances that preserved the deposits from erosion. Elsewhere along the outcrop belt, in areas less favorably situated for their preservation, the kaolin-bearing sediments have been reduced by pre-Holly Springs erosion and, in places, removed entirely.

The drilling disclosed the fact that the kaolin and associated sediments of the Ackerman formation occur in a basin which is roughly elliptical in outline. Whether this depression simply represents subsidence of the area due to weighting by the Ackerman sediments or is a pre-Ackerman structural or erosional basin is not fully established, but preliminary studies, using the base of the kaolin, Porters Creek top, and Holly Springs base as datum planes for contouring, all tend to show the existence here of certain well-defined depressions. Additional field studies, in conjunction with the data obtained from drilling, will be necessary to determine the origin and true character of this depression. Regardless of origin, this basin-like structure doubtless was very effective in preserving the kaolin from post-Ackerman erosion. The boundaries of this basin are greatly modified by erosion and were not accurately delimited by the drill explorations. It was found, however, that the kaolin deposits occur in a northeastward trending zone approximately 13,000 feet in length, about 3,000 feet wide at the northeast end and 5,000 feet wide at the southwest end. The northeastern kaolin deposit extends over approximately 23 acres, and the southwestern deposit over approximately 150 acres. It is believed that the two deposits are continuous, except where cut by erosion. A hole drilled in the narrow ridge which connects these areas penetrated the kaolin zone, but at a depth too great to permit economical mining. The kaolin beds were found to rest mainly on sand, and at the southern end of the southwestern deposit, this basal sand zone of the Ackerman formation crops out as a bar.

The kaolin beds, as exposed and as drilled in this area, are massive and show no major sedimentation breaks, except for a 6- to 8-inch zone near the top where small pellets of kaolin embedded in the massive matrix kaolin give it a pseudo-bauxitic appearance. The kaolin zone was found to be persistent throughout the area intensively drilled, the portion which met TVA specifications averaging 12 feet in thickness. The physical character of the kaolin is remarkably uniform throughout the area prospected. As seen in test pits, it is white to slightly grayish or creamy in color, very fine-grained, and is essentially free of sand. It dries to a good degree of whiteness, although the freshly dug damp kaolin commonly has a grayish cast. The dry clay also has a peculiar conchoidal fracture. Drilled samples of the kaolin showed variations in color ranging from creamy shades to shades of light gray, commonly marked by lignitic streaks.

Suggested Origin.—Although present knowledge of the West Tennessee kaolin-bearing deposits is essentially limited to the Clarksburg area, the writers suggest the following tentative hypothesis for the origin of these kaolins.

The kaolin beds in the Ackerman formation are believed to represent the product of deep laterization of an old Midway land surface, probably a peneplain developed on the Porters Creek clay in the long Midway-Wilcox interval, prior to invasion by the Wilcox seas. Both Rettger [9] in his Alabama investigations and Bramlette [10] in his Arkansas studies have shown that bauxite and associated materials occur immediately at the top of the Midway and that the beds are the product of prolonged sub-aerial laterization of the Porters Creek clays and, in Arkansas, of syenite. These zones of aluminous materials at the Midway top are comparable to, and apparently correlative with, the Betheden formation of Mississippi.[11] The time required for the formation of this leached Betheden zone in Mississippi, which there is reported to have a maximum thickness of 25 feet, is estimated at 1,000,000 years by Mellen.[12]

Pronounced chemical alteration of clays by sub-aerial weathering is a feature of tropical or sub-tropical climates, as is evidenced by the development of laterites in the tropic regions of the world today. The present hypothesis is compatible with this climatic prerequisite in that the Midway-Wilcox interval and succeeding Wilcox time were periods characterized by a sub-tropical climate, with abundant rainfall.[13] It is indicated further that at the beginning of Wilcox time, the Gulf Embayment region was a low, nearly featureless forested coastal plain, at or near base-level with the minimum of erosion favorable to the development of a thick mantle of residual clay and subsequent alteration by lateritic processes. The old Midway surface thus exposed to sub-aerial leaching doubtless extended for a considerable distance east of the present outcrop limits of the Porters Creek formation.

The long period of leaching during the Midway-Wilcox interval, as has been suggested by Conant,[14] probably developed on the old Midway surface a more or less continuous blanket of kaolin, and possibly bauxite in certain more favored localities. Shortly prior to deposition of the Wilcox sands, slight regional uplift, possibly a consequence of the invasion of the region by the early Ackerman seas, is believed to have caused rejuvenation of drainage on the old Midway surface. With this increased erosion, the kaolin residuum was swept off the old land surface and carried by streams to their present position, being laid down either as continental deposits in swampy offshore

[9] Rettger, R. E., The bauxite deposits of Southeastern Alabama. Econ. Geol., vol. 20, no. 7, 1925.

[10] Bramlette, M. N., Geology of the Arkansas bauxite region. Ark. Geol. Surv. Inf. Circ. 8, 1936.

[11] Mellen, F. F., Winston County mineral resources. Miss. State Geol. Surv. Bull. 38, 1939, pp. 26–27.

[12] Idem, p. 28.

[13] Berry, E. W., Lower Eocene floras of Southeastern North America, op. cit.; Revision of the Lower Eocene Wilcox flora of the Southeastern States, op. cit.

[14] Conant, L. C., Tippah County mineral resources. Miss. State Geol. Surv. Bull. 42, 1941, pp. 40–41.

lagoons or simply as deltaic deposits. The Carroll County kaolin deposits indicate these conditions of transportation and redeposition in the alternating sequences of lignites, kaolin, sands, and silty clays obtained in the drill-prospecting of this area. Similar occurrences of redeposited bauxite and other highly aluminous materials are described from the basal Ackerman sediments of Missouri [15] and of Mississippi.[16]

Nowhere in the area drilled in Carroll County is there conclusive evidence of the existence of remnants of an old altered Midway surface, like the Betheden formation of Mississippi, although it is possible that locally the kaolin-bearing strata may rest on such residual kaolin. In most instances, the kaolin beds were found to rest either on clean white sand or lignite. Further, at all observed outcrops, the basal Ackerman strata appear to rest unconformably on typical unaltered Porters Creek clays.

A series of similar basin-like deposits of kaolin and associated strata may have once existed parallel to the margin of the old Midway upland, but subsequent erosion may have largely removed these easternmost or basal Ackerman sediments. Hence, the fact that the Ackerman and Holly Springs formations in the Clarksburg area crop out farther east than most of the remainder of the outcrop belt of these formations may be partly responsible for preservation of the kaolin deposits, and this possibility must be considered in selecting areas for future exploration.

Possible Extensions of Ackerman Belt.—Investigations of the southward extensions of the Ackerman formation revealed conditions of occurrence very similar to those of the Clarksburg area, namely, great variability of sediments and rapid lateral changes. Locally the Ackerman sediments are completely absent, due either to non-deposition or to pre-Holly Springs erosion; one such unconformity was noted at Silerton, in northern Hardeman County, where the Holly Springs sands rest directly on Porters Creek clays. These unfavorable outcrop conditions preclude the possibility of direct geologic tracing of the kaolin zone from the Clarksburg area southward through the Ackerman belt. Further, no definite evidence of extensive kaolin deposits could be found in these southern areas, and only two localities—one each in Chester and Henderson counties—were noted as having clays of apparent promise. The Henderson County occurrence is less than 5 miles southwest of the Clarksburg area and may represent an extension of the kaolin deposit of that area. The negative evidence of these investigations, nevertheless, does not preclude the possibility that extensive kaolin deposits exist between the Clarksburg area and the Mississippi state line. Since completion of the present investigations, bauxite has been discovered in southern Hardeman County, near Middleton. The writers have not seen this find but oral descriptions of the strata associated with the bauxite indicate occurrence in the Ackerman formation.

[15] Stewart, D. R., McManamy, L., and McQueen, H. S., Occurrence of bauxitic clay in Stoddard County, Missouri. Mo. Geol. Surv. and Water Resources, 62nd Bien. Rept., Append. III, 1943.

[16] Conant, L. C., op. cit.; Union County mineral resources. Miss. State Geol. Surv. Bull. 45, 1942.

The Ackerman formation apparently thins rapidly through northern Carroll County and, locally, may be entirely absent over extensive areas because of either erosion or non-deposition. In Henry County, the Ackerman has not been identified north of Paris, and even at that city, as noted on the northern city limits along the Puryear highway, the Holly Springs sands rest unconformably on Porters Creek clays. Similar unconformable relations and absence of Ackerman sediments were observed farther north in the Puryear area near the Kentucky state line.

DIVISION OF INDUSTRIAL DEVELOPMENT,
STATE PLANNING COMMISSION,
432 6TH AVE. N.,
NASHVILLE 3, TENN.,
October 21, 1946.

DISCUSSION AND COMMUNICATIONS

DEPLETION OF MINERAL RESOURCES.

Sir: The recent paper of Professor Bateman [1] discussing wartime dependence on foreign minerals is not only very interesting, but it suggests also that the world as a whole will face a shortage of lead, zinc, copper and other metals which Mother Earth has until now supplied in abundance.

In another work [2] I have pointed out how the old Economic Liberalism is no longer up to date. Progress is going on, increased by a sort of acceleration which each year increasingly develops our industrial as well as our agricultural output. In so doing this very progress is devouring more of our mineral reserves, until one after another mines become exhausted. Even if other deposits may be found, what is lost is lost forever.

The way an acceleration p may develop is considered in a mathematical analysis that I shall recall here [3] in order to prove once again that a fatal and dynamic thrust is the motive power of our civilization which under such stimuli always produces more materials and more food as if the world were a giant never satiated.

If we designate by M the volume of our whole production, industrial as well as agricultural, and by W the rate of such production, by supposing W always the same for the same time t, we should have no progress at all, and in this case we may establish the following equation:

$$W = \frac{dM}{dt}. \tag{1}$$

We have already pointed out, however, that an acceleration p is part of a progressive world such as we have, let us say, the pleasure of living in, an acceleration that is pushing relentlessly forward the human society that doesn't know actually where it is going. The two world wars we have been through in this century would indicate it is unsettled, but let us hope men will become wiser in the long run, and less selfish too. At any rate, the acceleration p is a matter of fact, and for W in an ascensional movement of progress it may be determined as follows:

$$p = \frac{dW}{dt}$$
$$dW = pdt. \tag{2}$$

[1] Bateman, Alan M., ECON. GEOL., 1946, XLI: 308–327.
[2] Sagui, Cornelio L., L'Agriculteur de Provence et du Langue Doc, March, 1936.
[3] Sagui, Cornelio L., idem.

STATE COLLEGE OF AGRICULTURE AND APPLIED SCIENCE
JAN 9 1947
KANSAS

In equation (2) dW is the increment of the rate through which the production is accelerated in a time dt by an acceleration p, considered for simplicity constant. We shall then have:

$$W = \int p dt; \; t = \int \frac{dW}{p}.$$

From equation (2) we also have:

$$dt = \frac{dW}{p}.$$

If we now substitute dt in equation (1) we have:

$$W dW = p dM.$$

In order to simplify we put $p = l$, so M is found as follows:

$$M = \int W dW = \tfrac{1}{2} W^2.$$

And since $dt = dW$ when $p = l$ we obtain:

$$M = \tfrac{1}{2} K t^2$$

where K is a practical coefficient.

This result means that production, industrial and agricultural as a whole, is increasing as the square of time.

It is then no wonder that the American mineral resources are vanishing at an alarming pace. The same fate, however, is attending the rest of the world; and when Asia and other countries not yet as advanced in production enjoy the same industrial development we have already reached, the acceleration p above mentioned will certainly be increased and the mineral riches of the Earth, used on a more gigantic scale than they are used now, will consequently vanish more quickly.

The mathematical result found above points unequivocably to the fact that in less than a century we shall run short of a great number of mining products, since the discovery of new ores is not keeping pace with their consumption. At the same time the principal industrial States are already not only depleting their own ores but also those of the whole world at a high rate.

Metals beyond the borders of the present industrial nations will, of course, still be available. But as soon as the whole world reaches an industrial basis it is probable that economic and political influence will be shifted to countries richer in mines not already depleted. Consequently economic geology should be the principal tool in the hands of an industrial state in order to assure to its people the economic and political freedom it is accustomed to. Otherwise nothing can save it.

It is not only a question of reducing over-consumption and waste, which will prolong only a little the industrial life of a state. It seems necessary instead, in the light of our present history, to find out in world-wide cooperation a new economic system permitting an intercontinental distribution of natural resources of the world without custom defenses, which might otherwise become war incentives.

The time for isolationism seems to be over forever now. Europe, who has not understood this simple truth, has gone through two frightful wars and thus her powerful nations have been reduced to only a sad museum of past glories and present miseries.

CORNELIO L. SAGUI.

18 RUE LUCHET, AVIGNON, FRANCE,
October 21, 1946.

FOUNDATIONS OF THE HALES BAR DAM.

Sir: In the last number of this JOURNAL Mr. John W. Frink in an interesting paper, "The Foundations of the Hales Bar Dam," repeatedly misuses the word "cavitation."

The verb *to cavitate* means to create a vacuum in agitated air or water, as by a screw propeller or fan; *cavitation* means the causing of a vacuum to form, etc.

The Century dictionary offers a transitive verb "to cavern." Hence on page 596 Mr. Frink might have said, "lithology, structure, weathering, and *cavorning.*" At other places he might have used the word *cavern* or the phrase *formation of caverns.*

While everyone will probably understand his meaning, some may not be aware that a mistake has been made in the use of a word and hence may be led to repeat his error.

SIDNEY PAIGE

WAR DEPT., CORPS OF ENGINEERS,
NEW YORK,
Oct. 29, 1946.

COMMITTEE ON A NEW ROCK-COLOR CHART FOR FIELD USE.

A committee representing a number of geological societies and organizations has begun work on a new rock-color chart designed specifically for field use. The membership of the committee is as follows:

Parker D. Trask, representing the Geological Society of America.
Ronald K. DeFord, representing the American Association of Petroleum Geologists.
Joseph T. Singewald, Jr. and R. M. Overbeck, representing the Association of American State Geologists.
Olaf N. Rove, representing the Society of Economic Geologists.
E. N. Goddard, representing the U. S. Geological Survey.

The first meeting of the committee was held on May 2, 1946, in Washington, D. C. Hugh D. Miser, of the Geological Survey, who had been instrumental in getting the work started, gave a brief account of the discussions and correspondence that led up to the organization of the committee. Mr. DeFord, who was unable to attend, sent a letter suggesting a general plan of procedure, and this letter was used as a basis for discussion. The following plans were agreed upon by the committee.

1. The rock-color chart is to be based on the Munsell color system, the most widely accepted system of color identification in the United States.

2. Simple color names of the ISCC–NBS (Inter-Society Color Council-National Bureau of Standards) method are to be used on the chart, insofar as is applicable to field use. This method has already been adopted by a large number of societies and organizations interested in color.

3. In addition to the color names, the Munsell hue, value and chroma designations are to be put on the chart, for the use of any geologists who feel the need of numerical designations and fine color distinctions.

4. Sedimentary, igneous and metamorphic rocks (both consolidated and unconsolidated) are to be included, and also well cuttings. If possible, both wet and dry rocks are to be included.

The committee is now engaged in collecting and classifying the widest possible range of rock specimens in order to determine the range of colors needed on the chart. The next meeting of the committee is to be held at the Chicago meetings of the Geological Society of America in December, 1946, and at that time, the following problems will be considered:

1. The number and range of colors, and the appropriate names to be used on the chart.

2. The shape, size and arrangement of the chart, the size of the color tabs, and whether holes in the chart should be used to facilitate comparisons with rock samples.

3. The method and means of printing and distributing the chart.

The committee will welcome any suggestions. The Munsell color system, as applied to rock colors, is discussed by DeFord—Rock Colors: American Association Petroleum Geologists Bulletin, vol. 28, no. 1, pp. 128–137, January 1944. The ISCC–NBS method of naming colors is described by Dean B. Judd and Kenneth L. Kelly—Method of Designating Colors: National Bureau of Standards Research Paper No. 1239, September 1939.

REVIEWS

Principes de Géologie, 2nd ed. By P. FOURMARIER. 2 vols.; pp. 1,212; Figs. 674. Vaillant-Carmanne, Liége, Belgium, 1944.

The first edition of this important work appeared in 1933, and this edition has just recently become available to American readers. The size has been increased by about one-third, and many new illustrations appear. The author states in his preface that since 1933 there have been many advances in the mineral sciences, most of which are included in this new edition. He stresses the advances in chemistry and physical chemistry that have a bearing on the formation and evolution of rocks; observations on earthquakes, volcanic activity, and the distribution of gravity that throws light on the depth zones of the earth; and newer knowledge regarding surficial changes.

The former arrangement has generally been followed, with certain changes in the treatment of areal geology and the origin of rocks. The following list of topics gives an idea of the arrangement and the contents: (1) Fundamental Principles in eight chapters dealing with principles, rocks, their composition, classification and surficial alteration, the earth as a whole and its interior; (2) The Formation of Rocks in 17 chapters dealing with the origin of the different kinds of sedimentary, metamorphic and igneous rocks, including differentiation; (3) Evolution of Rocks in 12 chapters dealing with structural features, tectonics, evolution, igneous activity and evolution on the surface and in depth; (4) Areal Geology of the major divisions of the world with extended treatment of major structural features and tectonic theories; (5) Physical Geology in 10 chapters dealing with climatology, oceanography, geomorphology, paleogeography and paleoclimatology. This unusual arrangement of subject matter is new to most American readers, but it is comprehensive and interesting. Historical geology is treated in the detailed descriptions of areal geology, and the substances are dealt with before the processes that give rise to them. Mineral deposits occupy a page under magmatic differentiation and another one under tectonics.

This book is unquestionably the outstanding European textbook on the principles of geology and differs from most American advanced texts by its interesting and extensive treatment of areal geology.

Canadian Mines Handbook—1946 Edition. Pp. 404. Northern Miner Press, Toronto, Ontario. Price, $2.00.

This annual volume is, as usual, a compendium of information on the Canadian mining industry and reflects the post-war activity in Canadian mining. It lists some 1,765 live mining companies compared with 554 three years ago; 127 have been dropped into the inactive class and 150 have revived from dormancy; the year's gain is 465. Quebec, followed by Yellowknife, shows the most newcomers, but Ontario and British Columbia also reflect the changes in metal prices. The volume carries the significant details of each company, giving officers, development, ore reserves, capitalization, a five-year comparison of production, earnings and dividends, and other information. Active, quiescent and defunct companies are listed separately. It is a handbook of great value to those interested in Canadian mining.

BOOKS RECEIVED.

ALAN T. BRODERICK.

Preliminary Report on the Kokomo Mining District, Colorado. A. H. KOSCHMANN, F. G. WELLS. Pp. 62, pls. 2. Colorado Sci. Soc. Proc., Vol. 15, No. 2, Denver, 1946. *Stratigraphy and structure with brief description zinc-lead-silver deposits.*

Chromite Deposits of the North Elder Creek Area, Tehama County, California. G. A. RYNEARSON. Pp. 19, pls. 6, figs. 1, tables 3. U. S. G. S. Bull. 945–G. Washington, 1946. *Segregations in Dunite. Reserves of all classes 109,000 tons 10% Cr_2O_3, 4,000 tons 44% Cr_2O_3.*

Molybdenite Investigations in Southeastern Alaska. W. S. TWENHOFEL, G. D. ROBINSON, H. R. GAULT. Pp. 31, pls. 8, figs. 3. U. S. G. S. Bull. 947–B. Washington, 1946. *Low grade stockwork and fault zone deposit. Large reserves.*

Nickel Investigations in Southeastern Alaska. G. C. KENNEDY, M. S. WALTON, JR. Pp. 25, pls. 10, figs. 4. U. S. G. S. Bull. 947–C. Washington, 1946. *Largest U. S. owned nickel deposits, segregations in norite, principal reserves 20,700,000 indicated and inferred 0.31% Ni, 0.21% Cu.*

Geology and Associated Mineral Deposits of Some Ultrabasic Rock Bodies in Southeastern Alaska. G. C. KENNEDY, M. S. WALTON, JR. Pp. 19, pls. 4, figs. 3. U. S. G. S. Bull. 947–D. Washington, 1946. *Almost unlimited quantities of dunite available.*

Copper Bullion Claims, Rua Cove, Knight Island, Alaska. K. STEFANSSON, R. M. MOXHAM. Pp. 7, pls. 3, figs. 1. U. S. G. S. Bull. 947–E. Washington, 1946. *Mineralized shear zones in igneous rocks. Reserves 1.25% Cu or better; measured, 25,000 tons; indicated, 1,125,000; inferred, 264,000. Also estimated several million tons about .6% Cu.*

Copper Deposits of the Nizina District, Alaska. D. J. MILLER. Introd. by F. H. MOFFIT. Pp. 27, pls. 4, figs. 7. U. S. G. S. Bull. 947–F. Washington, 1946. *Brief description of mines, including Kennecott, 13 prospects. None believed promising enough to warrant reestablishing transportation to the district.*

Copper Deposits of the Kotsina-Kuskulana District, Alaska. R. E. VAN ALSTINE, R. F. BLACK. Introd. by F. H. MOFFIT. U. S. G. S. Bull. 947–G. Washington, 1946. *Brief description of location and geology of principal deposits, none of which is large or high-grade.*

Oregon Quicksilver Deposit Map. F. FREDERICK. 20″ × 26″, scale 1:1,000,000. Oregon Dept. Geol. & Min. Ind.

Contributions to Geochemistry 1942–45. R. C. WELLS AND OTHERS. Pp. 161 pls. 5, figs. 48. U. S. G. S. Bull. 950. Washington, 1946. *First bulletin of a new series concerning contributions of the Chemical Laboratory staff to chemistry, physics, mineralogy and related subjects. Improved methods of analysis, useful apparatus, end member formulas of micas, gelatinization of silicates, gamma-ray activity of potassium salts, discussion of atom arrangement in aluminosilicates.*

Report of the Government Geologist for the Year 1943. Pp. 30. Australia Dept. of Mines. Perth, 1944. *Individual reports on results of year's investigations at various mines in W. Australia.*

Developments in Eastern Interior Basin in 1945. A. H. BELL. Pp. 6, figs. 1, tables 2. Ill. Geol. Surv. Press Bull. 53. Urbana, 1946. *Oil pools discovered in 1945.*

Oil and Gas Development in Illinois in 1945. A. H. BELL, V. KLINE. Pp. 45, figs. 2, tables 7. Ill. Geol. Surv. Press Bull. 54. Urbana, 1946.

Mica Deposits of the Petaca District, Rio Arriba County, New Mexico, with Brief Descriptions of the Ojo Caliente District, Rio Arriba County, and the Elk Mountain District, San Miguel County. R. H. JAHNS. Pp. 294, pls. 26, figs. 28. New Mex. Bur. Mines & Min. Res. Bull. 25. Socorro, 1946. *Geology and mineralogy of individual deposits; economic features.*

Southern Illinois Novaculite and Novaculite Gravel for Making Silica Refractories. C. W. PARMELEE, C. G. HARMAN. Pp. 55, figs. 29, tables 16. Ill. Geol. Surv. Rep. of Investigations 117. Urbana, 1946. *Product is similar in appearance and properties to commercial silica brick from quartzite ganister.*

Agstone Used in Illinois in 1945. W. H. VOSKUIL, D. F. STEVENS. Pp. 9, maps, 1. Ill. Geol. Surv. Circ. 123. Urbana, 1946.

Use of Electrical Geophysical Methods in Groundwater Supply. C. A. BAYS. Pp. 13, photos 7, figs. 4. Ill. Geol. Surv. Circ. 122. Urbana, 1946. *Surface resistivity; electric well logs.*

Ground-Water Conditions in Elm Creek Valley, Barber County, Kansas, with Special Reference to Contamination of Ground Water by Oil-field Brine. C. C. WILLIAMS, C. K. BAYNE. Pp. 47, pls. 2, figs. 9, tables 4. State Geol. Surv. Kansas, Bull. 64, pt. 3. Lawrence, 1946.

Geology and Ground-Water Resources of Scotts Bluff County, Nebraska. L. K. WENZEL, R. C. CADY, H. A. WAITE. Pp. 150, pls. 12, figs. 14. U. S. G. S. Water-Supply Paper 1943. Washington, 1946. *Principal water supply in Pleistocene and Recent gravels.*

Tertiary Foraminifera from St. Croix, Virgin Islands. J. A. CUSHMAN. Note on Geology by D. J. CEDERSTROM. Pp. 17, figs. 2, distrib. chart. U. S. G. S. Pp. 210–A. Washington, 1946. *Miocene and Oligocene fauna from 3 wells.*

A Pennsylvanian Florule from the Forkston Coal in the Dutch Mountain Outlier, Northeastern Pennsylvania. C. B. READ. Pp. 27, pls. 2, figs. 1. U. S. G. S. P.P. 210–B. Washington, 1946. *May aid correlation of eastern Pennsylvania anthracite region with Allegheny Plateau Pennsylvania strata.*

Upper Cretaceous Foraminifera of the Gulf Coastal Region of the U. S. and Adjacent Areas. J. A. CUSHMAN. Pp. 241, pls. 66. U. S. G. S. P.P. 206. Washington, 1946. *Many excellent index fossils. Charts showing vertical distribution.*

Geology and Paleontology of Palos Verdes Hills, California. W. P. WOODRING, M. N. BRAMLETTE, W. S. W. KEW. Pp. 145, pls. 37, figs. 16. U. S. G. S. P.P. 207. Washington, 1946.

Preglacial Erosion Surfaces in Illinois. L. HORBERG. Pp. 13, figs. 5, tables 1. Ill. Geol. Surv. Rep. of Investigations 118. Urbana, 1946. *Data from bedrock topographic maps; peneplain correlations.*

Geology of the Northwestern Wind River Mountains, Wyoming. C. L. BAKER. Pp. 31, pls. 11, figs. 1. Geol. Surv. Wyo. Bull. 35. Laramie, 1946.

Cuadernos de Mineralogia y Geologia. Pp. 76. Universidad Nacional de Tucuman. Pub. 416, Tomo IV–C. 4, No. 16. Tucuman, Argentina, 1946. *Last issue under this title. Geology of Amaicha Ravine.*

Estudos, Notas e Trabalhos, do Ser. Fomento Mineiro, Vol. 1, Nos. 1 and 2, pp. 176, 3 and 4, pp. 330. Lisbon, 1945. *Twenty articles relating to bismuth, platinum, gold, copper, iron deposits and their reserves, magmatic differentiation products, and geophysical work; colored maps.*

SCIENTIFIC NOTES AND NEWS

FEDERICO AHLFELD, since 1935 Chief Geologist of the Direccion General de Minas y Petroleo, La Paz, Bolivia, is now Chief of the Mining Department of the Institute of Geology and Mines in Jujuy, Argentina.

VICTOR M. LOPEZ, Director of the Technical Service of Mines and Geology of Venezuela, has been awarded the "Medal of Freedom" (a bronze palm) by the War Department of the United States for "Exceptionally meritorious services in behalf of the Allied war effort from December, 1941, to July, 1946."

The American Book Center is collecting and shipping abroad scholarly books and periodicals which will be useful in research and necessary in the physical, economic, social and industrial rehabilitation and reconstruction of Europe and the Far East. WHAT IS NEEDED: Emphasis is placed on publications issued during the past decade, scholarly books which are important contributions to their fields, periodicals (even incomplete volumes) of significance, fiction and non-fiction of distinction. All subjects—history, the social sciences, music, fine arts, literature and especially the sciences and technologies—are wanted. WHAT IS NOT NEEDED: Textbooks; out-dated monographs; recreational reading; books for children; light fiction; materials of purely local interest; popular magazines such as *Time, Life, National Geographic;* popular non-fiction of little enduring significance. Only carefully selected federal and local documents are needed, and donors are requested to write directly to the Center with regard to specific documents. HOW TO SHIP: All shipments should be sent PREPAID via the cheapest means of transportation to THE AMERICAN BOOK CENTER, c/o THE LIBRARY OF CONGRESS, WASHINGTON 25, D. C. Although the Center hopes that donors will assume the costs of transportation of their materials to Washington, when this is not possible reimbursement will be made upon notification by card or letter of the amount due. THE CENTER CANNOT ACCEPT MATERIAL WHICH IS SENT COLLECT. Reimbursement cannot be made for packing or other charges beyond actual transportation. When possible, periodicals should be tied together by volume. It will be helpful if missing issues are noted on incomplete volumes.

ADDISON B. MANNING is now geologist for the Bay Petroleum Company in Denver. He was formerly with the Magnolia Petroleum Company of Dallas.

NEIL A. O'DONNELL has been elected executive vice-president of the Idaho Maryland Mines Corporation, Grass Valley, California, of which comany he is general manager.

RAY M. KNUTSON of the department of geology of the Bunker Hill and Sullivan Mining and Concentrating Company of Kellogg, Idaho, is now geologist at Gilman, Colorado, for the Empire Zinc division of the New Jersey Zinc Company.

WILLIAM E. B. PAPPERT has gone to Guam as consulting geologist for Frederick R. Harris.

GEORGE E. WOODWARD, chief, Mineral Economics Division, U. S. Bureau of Mines, has been assigned to compile a report on mineral resources and mineral economics of Japan.

GLENN G. BARTLE, formerly of E. Holley Poe and Associates of New York, is dean and professor of geology of the Triple Cities College of Syracuse University, Endicott, New York.

JACK W. CLARK has been assigned to carry out further exploration of the Iron Mountain, New Mexico, beryllium-zinc deposits as geologist for Spectrographic Services and Supplies, Inc., Saratoga Springs, New York.

BAHNGRELL W. BROWN, formery field engineer with the Arizona Department of Mineral Resources, is now stationed in Kyoto, Japan, with the 10th Chemical Service Company.

G. E. EDDY has been appointed Michigan state geologist to succeed R. A. Smith who has retired.

INDEX TO VOLUME XLI

(NOTE.—In this index the titles of principal papers and headings of departments, as *Reviews,* are in italics.)

Abrams, F. W., petroleum storage costs (review), 92
Abstracts—
Artificial recharge of artesian limestone at Orlando, Florida (Unklesbay and Cooper), 293
Artificial recharge of glacial sand and gravel with filtered river water at Louisville, Kentucky (Guyton), 644
Artificial recharge of ground water on Long Island, New York (Brashears), 503
Artificial recharge of productive groundwater aquifers in New Jersey, 726
Clarksburg kaolin area of Carroll County, Tennessee (Whitlatch and Gildersleeve), 841
Control of impounding structures on ore deposition (Mackay), 13
Correction factor for specific gravity and volume differences in fragment analysis, 749
Cotangent ruler for simplifying the graphic solution of problems in structural geology (White), 539
Ferruginous bauxite deposits in northwestern Oregon (Libbey, Lowry, and Mason), 246
Foundation displacements along the Malheur River siphon as effected by swelling shales (Mielenz and Okeson), 266
Foundation of Hales Bar Dam (Frink), 576
General principles of artificial groundwater recharge (Meinzer), 191
Genesis of ground waters in the coastal Plain of Virginia (Cederstrom), 218
Humic acids and true organic acids as solvents of minerals (Fetzer), 47
Hydrothermal alteration in the Castle Dome copper deposit, Arizona (Peterson, Gilbert, and Quick), 820
Landslides and their relation to engineering in the Dunedin district, New Zealand (Benson), 328
Lead-silver mineralization in the Clark Fork district, Bonner County, Idaho (Anderson), 105
Luminescent phenomena as aides in the localization of minerals in polished sections (Yagoda), 813
Microscopic characters of vein carbonates (Grout), 475
Mineral resources of China (Juan), 399
Abstracts—Continued
Movement of mineralizing solutions in the Picher field, Oklahoma-Kansas (Stoiber), 800
On the nature of replacement (Douglas, Goodman, and Milligan), 546
Notes on the cutting and polishing of thin sections (Meyer), 166
Notes on the ilmenite deposits at Piney River, Virginia (Davidson, Grout, and Schwartz), 738
Portable differential thermal analysis unit for bauxite exploration (Hendricks, Goldich, and Nelson), 64
Preliminary chemical correlation of chromite with the containing rocks (Thayer), 202
Punched card identification of ore minerals (Fairbanks), 761
Quartz crystal deposits in the State of Goiaz, Brazil (Campbell), 773
Quartz crystal deposits of western Arkansas (Engel), 598
Recent contributions to the geology of the Michigan copper district (Broderick, Hohl, and Eidemiller), 675
Relations of bauxite and kaolin in the Arkansas bauxite deposits (Goldman and Tracey), 567
Rôle of sulphur bacteria in the formation of the so-called sedimentary copper ores and pyritic ore bodies (Schouten), 517
Sedimentary and volcanic processes in the formation of high alumina clay (Allen), 124
Stages and epochs of mineralization in the San Juan Mountains, Colorado, as shown at the Dunmore mine, Ouray County, Colorado (Kelley and Silver), 139
Structural control of ore bodies in the Jefferson City area, Tennessee (Brokaw and Jones), 160
Synthetic replacements as an aid to ore-genetic studies (Schouten), 659
Tin and tungsten deposits of French Morocco (Heck), 383
Transport and deposition of the nonsulphide vein minerals. I. Introduction (Smith), 57
White Horse alunite deposit, Marysvale, Utah (Willard and Proctor), 619

Acids and true organic acids as solvents of minerals, Humic (Fetzer), 47
Acmite, 496
Adams, S. F., on quartz, 476, 483, 499
Adularia, 612, 832
Aikinite, 147
Alabama, aluminous clays, 841
Alaska, chromite, Kenai Peninsula, 215
Albite, synthesis, 59
Albitization, 44
Alexander, L. T., *et al.*, on soils, 574
Allen, E. T., Crenshaw, J. L., and Merwin, H. E., on sulphides, 58
Allen, V. T., *Sedimentary and volcanic processes in the formation of high alumina clay*, 124–138
on Ione formation, Calif., 125
and Fahey, J. J., on mansfieldite, 137
and Nichols, R. L., on clays, 128, 130
Allen's reaction, 61
Alpha-matildite, 767
Alteration, Clark Fork district, Idaho, 107
latite, Marysvale, Utah, 623
Michigan copper district, 688
Piney River ilmenite area, Va., 743
quartz deposits, Ark., 613
synthesis experiments, 59
tungsten deposits, China, 437
volcanic rocks to clay, 126
zoning, 44
Alteration in the Castle Dome copper deposit, Arizona, Hydrothermal (Peterson, Gilbert, and Quick), 820
Alumina clay, Sedimentary and volcanic processes in the formation of high (Allen), 124
Alunite, China, 405, 461
Alunite deposit, Marysville, Utah, White Horse (Willard and Proctor), 619
Alunitization, 627
Amblygonite, 62
Amethyst, Missouri (review), 90
Analyses (see Chemical Analyses)
Analysis, A correction factor for specific gravity and volume differences in fragment (Chayes), 749
Analysis unit for bauxite exploration, A portable differential thermal (Hendricks, Goldich, and Nelson), 64
Anderson, A. L., *Lead-silver mineralization in the Clark Fork district, Bonner County, Idaho*, 105–123
on mineral identification, 554
Anderson, R. J., on bournonite, 110
Andrews, D. A., and Schaller, W. T., on aragonite, 482
Anglesite, 361, 663, 667
Anhydrite, 60, 62
Ankerite, 60
Anthracite, China, 410
Antimony, 42
China, 403, 444
Clark Fork lead-silver ores, Idaho, 112
U. S., supplies in wartime, 313
Antithetic faults, 79, 85
Antozonite, 818
Apatite, 60, 62, 743, 831
China, 467
Applin, P. L., and Applin, E. R. on limestone, 296
Aquifers in New Jersey, Artificial recharge of productive ground-water (Barksdale and Debuchananne), 726
Aragonite, 479
Arizona, Hydrothermal alteration in the Castle Dome copper deposit (Peterson, Gilbert, and Quick), 820
ground water, Safford Valley, 193
Arkansas, The quartz crystal deposits of western (Engel), 598
ground water, Grand Prairie district, 198
Arkansas bauxite deposits, Relations of bauxite and kaolin in the (Goldman and Tracey), 567
Armstrong, H. E., on osmosis, 21
Arsenic, 42
China, 404, 450
Arsenides, Michigan copper district, 715
replacement, 661
Arsenopyrite, 110, 120, 450, 497, 669
Artesian limestone at Orlando, Florida, Artificial recharge of (Unklesbay and Cooper), 293
Artesian water, Coastal Plain, Va., 221
Asbestos, China, 466
U. S., supplies in wartime, 314
Asphalt, China, 421
Atom shunting and replacement, 547
Atomic power and uranium (review), 91
Autoluminographs, 816
Autunite, 814
Axlerod, J. M., on plagioclase, 829

Babcock, H. M., and Cushing, E. M., on ground water, 195
Bacteria, hydrobacteriology (review), 558
Bacteria in the formation of the so-called sedimentary copper ores and pyritic ore bodies, The rôle of sulphur (Schouten), 517
Baddelyite, 62
Bain, G. W., on carbonates, 493
on ore deposition, 36
on quartz, 607
Bandy, M. C., on crystals, 611
Barite, 112, 817
China, 461
synthesis, 59
Barksdale, H. C., and Debuchananne, G. D., *Artificial recharge of productive ground-water aquifers in New Jersey*, 726–737
et al., on ground water, 195
Barriers of ore-forming solutions, 17, 24
Barrow, L. T., petroleum, U. S. lands (review), 92
Baskerville, C., and Kunz, G. F., on autoluminographs, 816

Bastin, E. S., on calcite, 495
on carbonate, 486, 491, 497, 498
on colloform structures, 491
on sulphate reduction, 235
et al., on micro-metasomatism, 349
Bateman, A. M., *Wartime dependence on foreign minerals*, 308–327; discussion, 851
on minerals, 762
on replacement, 547
Bauer, E., on orthoclase, 59
Bauxite, China, 462
Bauxite and kaolin in the Arkansas bauxite deposits, Relations of (Goldman and Tracey), 567
Bauxite deposits in northwestern Oregon, Ferruginous (Libbey, Lowry, and Mason), 246
Bauxite exploration, A portable differential thermal analysis unit for (Hendricks, Goldich, and Nelson), 64
Bavendamm, W., on bacteria, 518
Becker, G. F., on sulphides, 58
Becquerel, A. C., on calcite, 59
Behre, C. H., Jr., reports by, 97, 183
Beidellite, 70, 829
Belgium, museum restoration plea (communication), 175
Bell, G. L., on bauxite, 258
Bell, J. F., on lucite, 166
Benjaminite, 766
Benson, W. N., *Landslides and their relation to engineering in the Dunedin district, New Zealand*, 328–347
on dolerite, 345
on landslides, 328
on lava flows, 328
Berg, G. E. W., on veins, 477
Berg, V. G., on breccias, 477
Berry, E. W., on Ackerman formation, 844
on Porters Creek formation, 846
Beryl, 60, 62
China, 467
fragment analysis, 752
U. S., supplies in wartime, 313
Bevan, A., memorial by, 186
Beyschlag, F., Vogt, J. H. L., and Krusch, P., on calcite, 501
Bibliography (review), 670
China, mineral resources, 471
ground water, Coastal Plain, Va., 244
Louisville area, Ky., 657
ground-water recharge, 200
Hales Bar Dam foundation, 597
ore minerals, identification, 767
petroleum (review), 285
quartz deposits, Goiaz, Brazil, 799
vein minerals, non-sulphide minerals, 63
Billings, M. P., on mapping methods, 539
Biotite, 830, 834
Bismuth, 42
China, 438, 440
Bismuthinite, 438, 440
Blanchard, R., and Hall, G., on lead-zinc ores, 348
Blanck, E., on iron, 54
Boehmite, 68, 73
Bog ores, China, 430
iron and manganese segregation, 55
Bolivia, copper, Coro Coro deposit, 711
Books received, 92, 178, 286, 393, 558, 671, 770, 856
Boreman, J. D., analysis by, 238
Bornite, 369, 379, 519, 523, 663
Boulangerite, 113
Bournonite, 110, 117
Boutwell, J. M., on carbonates, 496
Bowen, N. L., on chromite, 205
on magmas, 747
on water, 27
Boxwork, laminated quartz, 147
Boydell, H. C., on colloids, 26
Brackett, R. N., and Williams, J. F., on rectorite, 613
Bradley, W. H., communication by, 86
Bragg, W. L., on pyrite, 548
Bramlette, M. N., on bauxite, 848
Brammal, A., on tin, 38
Brannock, W. W., clay analyses by, 132
Brashears, M. L., Jr., *Artificial recharge of ground water on Long Island, New York*, 503–516
on ground water, 197, 504, 508
Brazil, Quartz crystal deposits in the State of Goiaz (Campbell), 773
Breccia, Dunmore mine, Colo., 144
Jefferson City area, Tenn., 164
latite, Marysvale, Utah, 623
limestone, Tenn., 590
Bretz, J. H., on caverns, 88
Bridgman, P. W., on fractures, 604
Broadgate, W. C., mining industries (review), 671
Broderick, A. T., books received, 770, 856
Broderick, T. M., on copper, 677, 684, 689
and Hohl, C. D., on copper, 677, 712
and Eidemiller, N. H., *Recent contributions to the geology of the Michigan copper district*, 675–725
Brokaw, A. L., and Jones, C. L., *Structural control of ore bodies in the Jefferson City area, Tennessee*, 160–165
Brookite, 607
Brown, J. A., petroleum, development and private enterprise (review), 92
Brown, J. S., review by, 88
Brown, W. L., on fluorite, 817
Bruce, E. L., discussion by, 282
on "porphyry," 283
Burbank, W. S., on mineralization, Ouray district, Colo., 155
on veins, San Juan Mtns., Colo., 157
Burger, M. J., on crystals, 606
Butler, B. S., on alunite, 620
and Burbank, W. S., on C. & H. Survey, 676
and Gale, H. S., on alunite, 620

Butts, C., on Bangor limestone, 587
Buwalda, J. P., on Idaho formation, Ore., 271

Cable, E. J., *et al.*, review of book by, 284
Cadman, W. H., on sulphate reduction, 235
Cadmium, monteponite, Sardinia, 767
Cady, R. C., on ground water, 219
Calaverite, 58
Calcite, 112, 479, 533, 613, 804
  frequency count technique, 756
  humic acid experiments, 55
  synthesis, 59, 62
California, chromite, composition, 208, 216
  clays, Ione deposit, 124
  ground water, Oakland region, 193
Callaghan, E., on alunite, 620
  on igneous rocks, 621
Campbell, D. F., *Quartz crystal deposits in the State of Goiaz, Brazil*, 773–799
Campbell, M. R., on coal, 415
Canada, mines handbook (review), 855
Cannon, R. S., Jr., and Murata, K. J., on scheelite, 814
Carbonates, 377, 533
  Microscopic characters of vein (Grout), 475
Card identification of ore minerals, Punched (Fairbanks), 761
Carr, R. S., natural resources symposium (review), 671
Cassiterite, 60, 62, 383, 437, 442, 498
Castle Dome copper deposit, Arizona, Hydrothermal alteration in the (Peterson, Gilbert, and Quick), 820
Cavitation, definition (discussion), 853
Cederstrom, D. J., *Genesis of ground waters in the Coastal Plain of Virginia*, 218–245
  on bicarbonate waters, 235
  on ground water, 218
Cerussite, 362
Cervantite, 446
Chalcocite, 453, 496, 519, 523, 663
  replacement of pyrite, 548, 553
Chalcopyrite, 89, 349, 366, 452, 496, 522, 664, 804, 823
Chaney, R. W., on Troutdale formation, Ore., 251
Chapman, E. P., on manganosiderite, 500
  and Stevens, R. E., on alpha-matildite (?), 767
Charlewood, G. B., on carbonates, 476, 500
Chayes, F., *A correction factor for specific gravity and volume differences in fragment analysis*, 749–760
  on fragment analysis, 749
Chemical analyses (review), 670
  bauxites, Oregon, 246, 256
  chromite, 205
  clays, Hobart Butte, Ore., 132
  latite, Marysvale, Utah, 623
  monzonites, Castle Dome area, Ariz., 836
  rocks, Hales Bar damsite, Tenn., 592
Chemical analyses—Continued
  slates, Nova Scotia, 548
  waters, Coastal Plain, Va., 222
Chemical correlation of chromite with the containing rocks, Preliminary (Thayer), 202
Chemical tests, carbonate, 477
Chemistry and science (review), 769
Chimneys, Dunmore mine, Colo., 139, 144
Chin, Y. H., on coal, China, 414
China, Mineral resources of (Juan), 399
Chlorite, 613, 669
  synthesis, 59
Christians, G. W., on asphalt, 583
Chromite, U. S., supplies in wartime, 314
Chromite with the containing rocks, Preliminary chemical correlation of (Thayer), 202
Cinnabar, 31, 449, 496
Clabaugh, S. E., *et al.*, review of maps by, 285
Clark, W. B., and Miller, B. L., on Coastal Plain, Va., 219
Clark Fork district, Bonner County, Idaho, Lead-silver mineralization in the (Anderson), 105
Clarke, F. W., on bauxite, 575
  on hot springs, 38
Clarksburg kaolin area of Carroll County, Tennessee. (Whitlatch and Gildersleeve), 841
Clay, Sedimentary and volcanic processes in the formation of high alumina (Allen), 124
  aluminum clay, China, 464
  Clarksburg kaolin deposit, Tenn., 841
  mineralogy, 828, 835
  thermal analysis, 65
Cleavage, mineral identification, 765
Cliachite, Oregon, 256
Clinohedrite, 818
Cloos, E., on feather joints, 83
  on joints, 605
Coal, China, 400, 408
Cobalt, 43
  replacement in ores, 661
  U. S., supplies in wartime, 315
Cocinerite, 766
Cole, W. S., on Lisbon formation, Fla., 296
Collins, W. H., *et al.*, on carbonates, 496
Colloids, mineralizing fluids, 57
Colombia, gold solution in humic acid, 50
Color, mineral identification, 764
  quartz crystals, Ark., 607
  rock color chart (communication), 853
Colorado, Stages and epochs of mineralization in the San Juan Mountains, Colorado, as shown at the Dunmore mine, Ouray County (Kelley and Silver), 139
Columbite, 60, 62, 819
Comb pockets, quartz, Ark., 610
Comb structure, 486

Comey, A. M., and Hahn, D. A., on copper, 52
Communications—
Appeal in favor of destroyed museums (Palache, *et al.*), 175
Committee on a new rock-color chart for field use, 853
Scientific and military cooperation (Eisenhower), 390
Veterans' retraining program in geology, Bradley, 86
Conant, L. C., on bauxite, 849
on leaching, 848
Concretions, Ackerman formation, Tenn., 845
pyrite, China, 458
Cone of elevation (ground water), 509
Conservation (review), 671
minerals (discussion), 851
Contact print identification, 764
Cooke, C. W., on Columbia group, Va., 221
on marl, 296
Cooper, H. H., Jr., with Unklesbay, A. G., *Artificial recharge of artesian limestone at Orlando, Florida*, 293–307
Copper, China, 403, 451
Cyprus, Skouriotissa pyrite deposit, 32
Dunmore mine, Colo., 144
humic acid experiments, 52
Messina district, Union South Africa (review), 769
Namaqualand deposits, 37
replacement, 663
U. S., supplies in wartime, 316
Copper deposit, Arizona, Hydrothermal alteration in the Castle Dome (Peterson, Gilbert, and Quick), 820
Copper district, Recent contributions to the geology of the Michigan (Broderick, Hohl, and Eidemiller), 675
Copper ores and pyritic ore bodies, The rôle of sulphur bacteria in the formation of the so-called sedimentary (Schouten), 517
Cores, Hales Bar damsite, Tenn., 585
Correlation of chromite with the containing rocks, Preliminary chemical (Thayer), 202
Corundum, 60
China, 467
U. S., supplies in wartime, 315
Cotton, C. A., on slumping, 347
Covellite, 537
Cratering ground water table, 507
Crawford, J. A., on zinc, 160
Cross, W., *et al.*, on Vallecito conglomerate, Colo., 141
Crumpler, T. B., and Yoe, J. H., on weight error, 751
Crust structure, carbonates, 486
Cryology, 2
Crystal deposits in the State of Goiaz, Brazil, Quartz (Campbell), 773
Crystal deposits of western Arkansas, Quartz (Engel), 598
Crystallography, quartz, Ark., 605
Crystals, growth and solution movement, 801
primary and secondary, 605
Cuba, chromite, composition, 203, 213
gold, Holguin deposit, carbonates, 490
Cumings, W. L., memorial of, 99
Currier, L. W., on zinc, 160
Cusset, F., review of book by, 670
Cutting and polishing of thin sections, Notes on the (Meyer), 166
Cyprus, pyrite, Skouriotissa deposit, 32

Dake, H. C., review of book by, 91
Dam, The foundation of Hales Bar (Frink), 576
Dana, J. D., on carbonates, 482
Darton, N. H., on ground water, 219
Datolite, 688
Daubrée, A., on sulphides, 58
Davidson, D. M., on ilmenite, 738
Grout, F. F., and Schwartz, G. M., *Notes on the ilmenite deposit at Piney River, Virginia*, 738–748
Davidson, N., analyses by, 836
Davy, W. M., and Farnham, C. M., on ore identification, 763
Dean, H. T., on fluorine, 231
Debris slides, New Zealand, 330
Debuchananne, G. D., with Barksdale, H. C., *Artificial recharge of productive ground-water aquifers in New Jersey*, 726–737
DeFord, R. K., on rock colors, 854
Deformation, carbonates of veins, 499
ore minerals and replacement, 371
quartz deposits, Ark., 615
sulphides, Clark Fork, Idaho, 108
DeGolyer, E., review of book by, 285
De Lapparent, J. L., on boehmite, 70
DeMent, J., review of book by, 91
Dennen, W. H., on molybdenite (?), 766
Denning, R. M., on scorodite, 137
Deposition, The control of impounding structures on ore (Mackay), 13
Deposition of the non-sulphide vein minerals. I. Introduction. Transport and (Smith), 57
Derrick, D. M., analyses by, 222
Derry, D. R., on drag folds, 34
Deuteric action, ilmenite ore, Va., 738
Deville, S. C., on quartz, 59
Diagrams—
alteration and mineralization, Castle Dome, Ariz., 824, 827, 839
block diagrams, Dunedin district, New Zealand, 341
cavitation treatment, Tenn., 585
chromite and anorthite, Cuba, 203
clays, stratigraphy, Ore. and Wash., 127
cotangent ruler and structure, 540
elements in vein minerals, 60

Diagrams—Continued
fault, Pachuca, Mexico (discussion), 82
greenstone and sediments, Mich., 685
ground water, composition, Va., 240
latite alteration, Utah, 630
micro-pseudomorphs among sulphides, 353, 534
microscopy of fluorescence, 815
paragenesis, lead-silver ore, Clark Fork, Idaho, 121
ores, Dunmore mine, Colo., 153
quartz deposits, Ark., 612
pore spaces between particles, 18
Portland area, Ore., 250
pyrite, atomic structure, 549
quartz crystal pocket, Ark., 611
solution movement directions, Picher district, Okla.-Kan., 810
thermal analysis unit, 66
well hydrographs, Louisville, Ky., 654
wells, temperature and salinity, Long Island, N. Y., 511
Dialysis, 17
Diamonds, China, 467
U. S., supplies in wartime, 316
Diaspore, 70
Dickite, 613
Dictionary, French-English and English-French (review), 670
Dikes, Clark Fork, Idaho, 123
Cuba, Guillermina, 205
Dunmore mine area, Colo., 141
Malheur Butte, Ore., 271
Mexico, Pachuca area (discussion), 77
nelsonite, Piney River, Va., 745
sand, Clarksburg area, Tenn., 844
Discussions and communications—
Depletion of mineral resources (Bateman), Sagui, 851
Foundations of the Hales Bar Dam (Frink), Paige, 853
Hardrock "porphyry" of Little Long Lac (Reid), Bruce, 282
Lead-silver mineralization in the Clark Fork district (Anderson), Fairbanks, 554
Some applications of structural geology to mining in the Pachuca-Real del Monte area, Pachuca silver district, Mexico (Thornburg), Wisser, 77
Source of ores (White), Thompson, 173
Displacements along the Malheur River siphon as effected by swelling shales, Foundation (Mielenz and Okeson), 266
Ditte, A., on sulphides, 58
Dolomite, 804
synthesis, 59
Dominican Republic, bauxite, exploration, 64
Donnay, J. D. H., on mineral identification, 761
Donnell, O. D., on petroleum exploration (review), 92
Douglas, G. V., on hydrodynamics, 547
Goodman, N. R., and Milligan, G. C., *On the nature of replacement,* 546–553
et al., on carbonates, 478
on slates, 547
Dow, D. H., *et al.,* review of maps by, 285
Dreyer, R. M., on mercury sulphide, 27
Drilling, Michigan copper district, 719
Dunham, K. C., on dunhamite, 767
Dunhamite, New Mexico, 767
Dunlap, J. C., on barite, 164
Dunmore mine, Ouray County, Colorado, Stages and epochs of mineralization in the San Juan Mountains, Colorado, as shown at the (Kelley and Silver), 139
Dunn, J. A., review of book by, 91
Dutrochet, —., on exosmosis, 15

Ebert, F. C., on ground water, 193
Economic geology, Hydrology in relation to (Meinzer), 1
Eidemiller, H. N., with Broderick, T. M., and Hohl, C. D., *Recent contributions to the geology of the Michigan copper district,* 675–725
Eisenhower, D., communication by, 390
Electrum, pseudomorphic after marcasite, Bantam, N. E. I., 381
Elements in vein minerals, 60
Ellsworth, H. V., on silver, 486, 498
Emmons, S. F., on siderite, 482
Irving, J. D., and Loughlin, G. F., on lead-zinc deposition, 36
Emmons, W. H., on carbonates, 500
on cupolas, 34
on metals, 42
and Calkins, F. C., on carbonates, 489
Enargite, 158, 452
Endellite, 70
Endosmosis, 45
Engel, A. E. J., *The quartz crystal deposits of western Arkansas,* 598–618
Engineering in the Dunedin district, New Zealand, Landslides and their relation to (Benson), 328
England, lead-zinc deposition, 36
English-French dictionary (review), 670
Enrichment, Castle Dome copper deposit, Ariz., 825
Clark Fork district, Idaho, 112
Ericson, D. B., on limestone, 296
Eve, A. S., and Keys, D. A., on electric currents, 553
Ewing, M., on Coastal Plain sediments, Va., 219
Exosmosis, 13
Experiments, asphalt grouting, Hales Bar damsite, Tenn., 583
fault simulation with clay, 85
metals in humic acids, 50
replacement by atom shunting, 551
soils, expansion-consolidation tests, 273
vein minerals, crystallization, 58

Exploration, A portable differential thermal analysis unit for bauxite (Hendricks, Goldich, and Nelson), 64
copper deposits, Michigan, 719

Fairbairn, H. W., on quartz, 608
Fairbanks, E. E., *The punched card identification of ore minerals*, 761–768
discussion by, 554
on electrolytes, 764
Fanning, L. M., review of book edited by, 92
Farmin, R., on breccias, 477
Farnham, C. M., on mineral identification, 554
on tarnishing reactions, 761
Faults, Castle Dome area, Ariz., 823
Clark Fork district, Idaho, 105
Columbia-Washington Counties, Oregon, 251
Hales Bar damsite, Tenn., 591
Jefferson City area, Tenn., 160
Keweenaw Peninsula, Mich., 680, 699, 703
Messina district, Union South Africa (review), 769
Mexico, Pachuca silver area (discussion), 77
quartz deposits, Arkansas, 602
Goiaz, Brazil, 780, 783, 797
Raibl Valley, Italy, 29
San Juan Mtns., Dunmore mine, Colo., 139
White Horse alunite deposit, Utah, 639
Fearnsides, W. G., on pyrite, 483
Feldman, C., analysis by, 626
Feldspar, 376, 687, 740, 819
Fellenius, W., on arcs of rupture, 343
Ferguson, H. G., and Gannett, R. W., on carbonates, 483
on quartz, 607
Ferguson, W. H., petroleum, public and naval reserves, U. S. (review), 92
Ferruginous bauxite deposits in northwestern Oregon (Libbey, Lowry, and Mason), 246
Fetzer, W. G., *Humic acids and true organic acids as solvents of minerals*, 47–56
on gold, 47
Field geology (review), 670
Fischer, R. P., on valleriite, 767
Fisher, D. J., on slope scales, 541
Florida, Artificial recharge of artesian limestone at Orlando (Unklesbay and Cooper), 293
ground water, Pensacola supplies, 194
Fluorine, ground-water distribution, Va., 231
Fluorite, China, 459
fluorescence and phosphoresence, 817
synthesis, 59
Folds, Columbia-Washington Counties, Oregon, 251
Dunedin district, New Zealand, 329
Dunmore mine area, Colo., 142
Hales Bar damsite, Tenn., 590
Jefferson City area, Tenn., 160
Malånäs district, Sweden (review), 668
quartz deposits, Arkansas, 600
Goiaz, Brazil, 781, 783, 786
White Horse alunite deposit, Utah, 632
Ford, W. E., on carbonates, 476
Formation of high alumina clay, Sedimentary and volcanic processes in the (Allen), 124
Formation of the so-called sedimentary copper ores and pyritic ore bodies, The rôle of sulphur bacteria in the (Schouten), 517
Forrester, J. D., review of book by, 670
Foster, M. D., analyses by, 132, 222
on sulphates, 236
Foundation displacements along the Malheur River siphon as effected by swelling shales (Mielenz and Okeson), 266
Foundation of Hales Bar Dam (Frink), 576; discussion, 853
Fourmarier, P., review of book by, 855
Fowler, G. M., on Boone formation, 808
on ore localization, 812
and Lyden, J. P., on fracture pattern, 809
on Miami trough, Okla.-Kan., 810
Fox, P. P., on solution rate, 593
Fragment analysis, A correction factor for specific gravity and volume differences in (Chayes), 749
Frebold, G., on inclusions, 369
Freieslebenite, 114, 119
Freise, F. W., on gold, 47
French-English dictionary (review), 670
Freundlich, H., on ultrafiltration, 16
Friedel, C., and Friedel, G., on orthoclase, 59
and Sarasin, E., on quartz, 59
Friedel, G., and Grandjean, —., on chlorite, 59
Frink, J. W., *The foundation of Hales Bar Dam*, 576–597; discussion, 853
on breccia, 590
on limestone, 593
Froehling, —., and Robertson, —., analysis by, 238
Fuller, M. L., on ground water, 197
Funk, N. E., water and power industries (review), 671

Galbraith, F. W., on petzite (?), 767
Galena, 31, 108, 120, 351, 446, 452, 455, 496, 523, 660, 801
Gallagher, D., on albitization, 44
Garrels, R. M., on ores, 38, 46
on sulphides, 57
Gaubert, P., on carbonates, 478

Gaudin, A. M., on films, 766
and Spedden, H. R., on mineral identification, 762
Gaudin, E., on molecules and unit crystals, 19
Gavelin, S., review of monograph by, 668
Geiger, A. T., analysis by, 228
Genesis, alunite, White Horse area, Utah, 640
ilmenite, Piney River, Va., 745
lead-silver ores, Clark Fork, Idaho, 123
ores (discussion), 173
pyrite, Missouri (review), 88
quartz crystals, Ark., 604
sulphide deposition by bacteria, 529
Genesis of ground waters in the Coastal Plain of Virginia (Cederstrom), 218
Geochemistry, elements in vein minerals, 60
Geocronite, 114
Geography (review), 177
Geohydrology, 2
Geological maps—
Castle Dome area, Ariz., 822
Dunedin district, New Zealand, 329
Dunmore mine area, Colo., 142, 145
Louisville area, ground water level, Ky., 647
Malheur River siphon, Ore., 278
Mezica area, Yugoslavia, 31
Noranda mine, Que., 33
Picher field, Oklahoma-Kansas, 807
quartz crystal deposits, Ark., 601
White Horse alunite deposit, Utah, 627
zinc ores, Jefferson City area, Tenn., 163
Geologists, professional work (review), 557
Geology, Hydrology in relation to economic (Meinzer), 1
alunite deposits, Utah, 621
bauxite deposits, Oregon, 259
Castle Dome copper deposit, Ariz., 821
Clark Fork district, Idaho, 105
Coastal Plain, Virginia, 219
Dunmore mine, San Juan Mtns., Colo., 140
Hales Bar damsite, Tenn., 587
Long Island, N. Y., 506
Louisville district, Ky., 645
Malånäs district, Sweden (review), 668
Messina copper district, Union South Africa (review), 769
Mexico, Pachuca silver area (discussion), 77
Orlando area, Florida, 295
quartz deposits, Arkansas, 600
Goiaz, Brazil, 775, 780, 783, 792
textbook (review), 855
Geology as a profession (review), 557
Geology of the Michigan copper district, Recent contributions to the (Broderick, Hohl, and Eidemiller), 675
Geophysical prospecting, Keweenaw Peninsula, Mich., 680, 722
Malånäs district, Sweden (review), 668
Georgia, aluminous clays, 841
German for the scientist (review), 558
Germany, ground water, recharge at Hamburg, 194, 196
micro-pseudomorphs in sulphides, Rammelsberg, 362
sulphides, formation by bacteria, 521
replacement, 661
Getchell, R. W., *et al.*, review of book by, 284
Gibbsite, 67, 69, 127, 255, 569
Gilbert, C. M., Quick, G. L., with Peterson, N. P., *Hydrothermal alteration in the Castle Dome copper deposit, Arizona*, 820–840
Gilbert, G. K., on joint veins, 487
Gildersleeve, B., with Whitlatch, G. I., *Clarksburg kaolin area of Carroll County, Tennessee*, 841–850
Gillett, C. A., forest products industries (review), 671
Gilluly, J., review by, 668
Glauconite, Virginia, 234
Glover, S. L., on clays, 127
Goethite, 70, 256, 355, 357
Goiaz, Brazil, Quartz crystal deposits in the State of (Campbell), 773
Gold, 497
China, 404, 456
Cuba, Holguin deposit, carbonates, 490
deposition and structural control, 37
humic acid experiments, 47
Tanganyika and Nigeria, structure of deposits, 33
Goldich, S. S., with Hendricks, S. B., and Nelson, R. A., *A portable differential thermal analysis unit for bauxite exploration*, 64–76
Goldman, M. I., and Tracey, J. I., Jr., *Relations of bauxite and kaolin in the Arkansas bauxite deposits*, 567–575
Goldschmidt, V. M., on pyrite, 548
Goodman, N. R., with Douglas, G. V., and Milligan, G. C., *On the nature of replacement*, 546–553
Grantham, D. R., on Lupa goldfield, Tanganyika, 33
Graphic solution of problems in structural geology, A cotangent ruler for simplifying the (White), 539
Graphite, 352
China, 467
U. S., supplies in wartime, 317
Graphs—
alunite, grade variations, Utah, 641
bauxites, thermal analysis, 67
chromite, composition, 210
ground-water movements, Long Island, N. Y., 507
minerals imported into U. S., 313
soils, time-consolidation curves, 276
water analyses, Coastal Plain, Va., 224
water velocities in aquifers, 304

Graton, L. C., on solutions, 26
on vein minerals, 58
and McKinstry, H. E., on carbonates, 494, 497
Gravel with filtered river water at Louisville, Kentucky, Artificial recharge of glacial sand and (Guyton), 644
Grawe, O. R., review of book by, 88
Gray, A. N., review of book by, 393
Greisen, tungsten deposits, China, 437
Griggs, D., on joints, 605
Grim, R. E., and Rowland, R. A., on thermal analysis, 65
Grondijs, H. F., and Schouten, C., on ores, 348, 659
Ground water, Malheur River siphon area, Ore, 276
recharge, Louisville, Ky., 644
Ground water on Long Island, New York, Artificial recharge of (Brashears), 503
Ground waters in the Coastal Plain of Virginia, Genesis of (Cederstrom), 218
Ground-water aquifers in New Jersey, Artificial recharge of productive (Barksdale and Debuchananne), 726
Ground-water recharge, General principles of (Meinzer), 191
Grout, F. F., *Microscopic characters of vein carbonates*, 475–502
on mineral particle shape, 750
with Davidson, D. M., and Schwartz, G. M., *Notes on the ilmenite deposit at Piney River, Virginia*, 738–748
Grouting, Hales Bar damsite, Tenn., 578
Gruner, E., on muscovite, 59
Gruner, J. W., on iron, 54
on orthoclase, 59
Guano, China, 467
Guild, F. N., on carbonates, 486
Guild, P. W., on chromite, 215
Guitermanite, 114, 117
Gutzeit, G., on contact print identification, 764
Guyton, W. F., *Artificial recharge of glacial sand and gravel with filtered river water at Louisville, Kentucky*, 644–658
on ground water, 193
et al., on water supply, 198
Gypsum, 60, 62
China, 465

Haffner, B. K., identification of ferrodolomite, 488
Hague, J. D., on scorodite, 136
Haiti, bauxite, exploration, 64
Hales Bar Dam, The foundation of (Frink), 476
Halloysite, 70
Halse, E., on veins, 477
Hardness of minerals, 765
Hardystonite, 817
Harlton, B. H., on Ouachita deformation, 618
Harrar, N. J., on iron, 54
Harrison, J. B., on gibbsite, 573
Harrison, J. V., and Falcon, N. L., on dip alteration, 338
Head, R. E., on mineral identification, 762
Heald, K. C., coal and shale reserves (review), 92
Heck, E. T., *Tin and tungsten deposits of French Morocco*, 383–389
Hector, J., on clay, 338
Hematite, 60, 139, 146, 429
Missouri (review), 89
Hendricks, S. B., Goldich, S. S., and Nelson, R. A., *A portable differential thermal analysis unit for bauxite exploration*, 64–76
and Alexander, L. T., on clays, 65
Heroy, W. B., oil and gas industries (review), 671
Hewett, D. F., on ores, 38
and Pardee, J. T., on manganosiderite, 481
Hillebrand, W. F., and Lundell, G. E. F., on carbonates, 478
Hiller, T., on contact print identification, 764
Hohl, C. D., with Broderick, T. M., and Eidemiller, H. N., *Recent contributions to the geology of the Michigan copper district*, 675–725
Holden, R. J., memorial of, 186
Holman, E., petroleum, U. S. foreign investments (review), 92
Honess, C. W., on quartz, 604
Hou, T. F., on arsenic, 450
on coal, China, 414
Howell, J. V., on metamorphic rocks, 476
Hsieh, C. Y., on oil, China, 423
Huebnerite, 146
Hulin, C. D., on ore deposition, 34
Humic acids and true organic acids as solvents of minerals (Fetzer), 47
Hunt, C. B., review of book by, 556
Hunter, J. C., on oil and gas conservation (review), 92
Hutchinsonite, 766
Hydrobacteriology (review), 558
Hydrodynamics of replacement, 546
Hydrogenation, coal, China, 423
Hydrology in relation to economic geology (Meinzer), 1
Hydrothermal alteration in the Castle Dome copper deposit, Arizona (Peterson, Gilbert, and Quick), 820
Hypofiltration, 14

Idaho, Lead-silver mineralization in the Clark Fork district, Bonner County, (Anderson), 105
Identification of ore minerals, The punched card (Fairbanks), 761

Igneous rocks, color chart, 853
Marysvale, Utah, 621
porphyry or arkose, Little Long Lac, Ont., 282
Iimori, S., and Iwase, E., on fluorite, 817
Ilmenite, 60, 62, 378, 530
Ilmenite deposit at Piney River, Virginia, Notes on the (Davidson, Grout, and Schwartz), 738
Inclusions, 367
India, mining handbook (review), 91
Industry and chemistry (review), 769
Intergrowths, ilmenite and magnetite, Va., 744
pyrrhotite, ilmenite, and magnetite, 530
sulphide minerals, 663
Iron, 43
bog limonite, Oregon, 247
China, 400, 424
humic acid experiments, 53
minerals in clays, 137
Missouri, pyrite (review), 88
Irving, J. D., on carbonates, 483
Isotropism and mineral identification, 765
Italy, mercury, Idria deposit, 31
monteponite, Sardinia, 767
Raibl Valley, ore deposits, 29

Jacob, C. E., *et al.*, on water supplies, 194
Jaffe, H., on fragmental analysis, 758
Jaggar, T. A., review of book by, 177
Jamaica, lateritic soil, thermal analysis, 67
Jamesonite, 497
Jeffords, R. M., on ground water, 193
Jenney, C. P., on gold, 38
Johannsen, A., on deuteric changes, 747
Johnson, M. E., memorial by, 99
Johnston, W. D., Jr., on carbonates, 482, 497
on quartz, 775
Joints, Dunmore mine, Colo., 143
feather joints, Pachuca area Mexico (discussion), 83
quartz deposits, Goiaz, Brazil, 780, 786
White Horse alunite deposit, Utah, 633
Jones, C. L., with Brokaw, A. L., *Structural control of ore bodies in the Jefferson City area, Tennessee*, 160–165
Jones, H. C., on osmosis, 15
on solutions, 22
Jordanite, 114, 117
Juan, V. C., *Mineral resources of China*, 399–474
Judd, D. B., and Kelly, K. L., on color, 854
Judd, J. W., on quartz, 607
Just, E., natural resources (review), 671

Kadesch, W. H., *et al.*, review of book by, 284
Kalb, G., on quartz, 608
Kania, J. E. A., on sulphides, 58
Kansas, Movement of mineralizing solutions in the Picher field, Oklahoma (Stoiber), 800
Kaolin, China, 464
Kaolin area of Carroll County, Tennessee, Clarksburg (Whitlatch and Gildersleeve), 841
Kaolin in the Arkansas bauxite deposits, Relations of bauxite and (Goldman and Tracey), 567
Kaolinite, 70, 126, 624, 628
Keller, W. D., and Moore, G. E., on carbonates, 478
Kelley, V. C., on mineralization, San Juan Mtns., Colo., 158
and Silver C., *Stages and epochs of mineralization in the San Juan Mountains, Colorado, as shown at the Dunmore mine, Ouray County, Colorado*, 139–159
Kelly, W. P., and Liebig, G. R., Jr., on ground water, 241
Kennedy, G. C., on bonding agents, 167
Kennedy, W. Q., on calcite, 498
Kent, D. F., and Rodgers, J., on zinc, 164
Kentucky, Artificial recharge of glacial sand and gravel with filtered river water at Louisville (Guyton), 644
Kerr, R. S., States and natural resources (review), 671
Kingston, S. P., on water, 300
Kirchberg, H., on carbonates, 478
Kirkham, V. R. D., on Idaho formation, Ore., 271
Klaer, F. H., Jr., and Kazmann, R. G., on water supplies, 194
and Thompson, D. G., on ground water, 194
Knopf, A., on ankerite, 493
Kolthoff, I. M., and Sandell, E. B., on carbonates, 478
Kremastic water, 2
Krieger, P., on carbonates, 488
Krumbein, W. C., and Pettijohn, F. J., on mineral particles, 750
Kummel, H. B., memorial of, 99

Laccoliths, Utah, Henry Mtns. (review), 556
Lahee, F. H., on mapping methods, 539
Lakes, ground-water rechargers, N. J., 729
Landslides and their relation to engineering in the Dunedin district, New Zealand (Benson), 328
Lane, A. C., on copper, 712
Langford, G. B., on carbonates, 501
Larrabee, D. M., *et al.*, review of maps by, 285
Larsen, E. S., and Berman, H., on carbonates, 476
Larsenite, 817
Laterite, thermal analysis, 74
Laterization, basalts, Oregon, 252
Midway surface, Tenn., 848
Lavas, Marysvale area, Utah, 621, 640
Michigan copper district, 679

Lead, China, 403, 453
Clark Fork district, microscopy, Idaho, 554
dunhamite, New Mexico, 767
Picher district, solution movement, 800
Sweden, Malånäs district (review), 669
U. S., supplies in wartime, 318
Yugoslavia, Mezica deposit, 29
Lead-silver mineralization in the Clark Fork district, Bonner County, Idaho (Anderson), 105
Le Chatelier, H., on thermal analysis, 65
Leggett, F. L., on grouting, 578
Leggette, R. M., and Brashears, M. L., Jr., on ground water, 504
and Taylor, G. H., on ground water, 193
Lemberg, J., on calcite, 59
Lepidocrocite, 357
Li, K. C., and Wang, C. Y., on tungsten, 439
Libbey, F. W., Lowry, W. D., and Mason, R. S., *Ferruginous bauxite deposits in northwestern Oregon*, 246–265
et al., on bauxite, 247, 264
Liddell, D. M., review of book by, 284
Lignite, China, 408
humic acid extraction, 48
Limestone, analyses, Hales Bar damsite, Tenn., 592
solution structures, Missouri (review), 88
Limestone at Orlando, Florida, Artificial recharge of artesian (Unklesbay and Cooper), 293
Limnology, 2
Limonite, 793
Oregon, 247
Lindgren, W., on barriers, 24
or carbonates, 486, 493, 495
on copper, 713
on inclusions, 483
on Ione formation, Calif., 124
on magmas, 174
on metasomatism, 476
on pseudomorphs, 349
on solutions, 123
on titanium, 746
and Bancroft, H., on calcite, 494
and Loughlin, G. F., on vein carbonates, 489
and Ransome, F. L., on carbonates, 496, 499
Lindner, J. L., and Gruner, J. W., on metals, 58
Linnaeite, 537
Liu, C. P., on lead, 455
Locke, A., on ore deposition, 34
Lohr, E. W., analyses by, 222
Long Island, New York, Artificial recharge of ground water on (Brashears), 503
Longwell, C. R., on faults, 86
Loughlin, G. F., on alunite, 620
on carbonates, 477
Louisville, Kentucky, Artificial recharge of glacial sand and gravel with filtered river water at (Guyton), 644
Love, S. K., analysis by, 228
Lovejoy, J. M., oil technology (review), 92
Lovering, T. S., on alteration, 826
on beidellite, 829
on iron, 54
Lowry, W. D., with Libbey, F. W., and Mason, R. S., *Ferruginous bauxite deposits in northwestern Oregon*, 246–265
Luminescent phenomena as aides in the localization of minerals in polished sections (Yagoda), 813
Lungwitz, E. E., on gold, 50
Lyotropic series, 14, 20

McConnell, D., on bentonitic clays, 273
MacDonald, D. F., on ground movement, 343
Mackay, R. A., *The control of impounding structures on ore deposition*, 13–46
on gold, 33
on strata, 24
McKinstry, H. E., on a protractor, 541
McKnight, E. T., on carbonates, 482
MacPherson, F. H., on bauxite, 264
McQueen, H. S., on sinks, Missouri (review), 89
Maffitt, D. L., on ground water, 196
Magmas, 173
chromite formation and silica, 207
Magnesite, China, 405, 465
Magnetite, 60, 62, 429, 498, 743
oolites in bauxite, Ore., 255
Malachite, Missouri (review), 90
Malheur River siphon as effected by swelling shales, Foundation displacements along the (Mielenz and Okeson), 266
Manganese, China, 433
humic acid experiments, 53
U. S., supplies in wartime, 317
Mansfieldite, 137
Maps, Arizona, Globe Quadrangle, 821
Arkansas, quartz crystal deposits, 600
bauxites, Oregon, 249
China, mineral resources, 401, 468
Clark Fork district, Idaho, 106
Florida and Georgia, ground water surface, 297
Hales Bar damsite, Tenn., 577
Keweenaw Peninsula, Mich., 678
Louisville area, Ky., 646
Marysvale region, Utah, 622
Missouri Valley, mineral resources (review), 285
Morocco, French, tin and tungsten deposits, 384
New Jersey, ground-water recharge fields, 728
New York, Long Island, ground water surface, 505
Piney River ilmenite area, Va., 739

STATE COLLEGE OF AGRICULTURE AND APPLIED SCIENCE
JAN 9 1947
KANSAS

Maps—Continued
quartz deposits, Goiaz, Brazil, 774
Raibl Valley, Italy, 30
Tennessee, Clarksburg kaolin deposit, 842
water types, east Virginia, 220
Marcasite, 359, 523, 804
Missouri (review), 88
Martens, J. H. C., mineral identification by, 383
Marysvale, Utah, White Horse alunite deposit (Willard and Proctor), 619
Maschke, O., on quartz, 59
Mason, R. S., with Libbey, F. W., and Lowry, W. D., *Ferruginous bauxite deposits in northwestern Oregon*, 246–265
Mather, W. B., on carbonates, 497
Mattei, A. C., petroleum, U. S. lands (review), 92
Mead, W. J., on bauxite, 570
on faults, 84
on fractures, 605
Meinzer, O. E., *General principles of artificial ground-water recharge*, 191–201
Hydrology in relation to economic geology, 1–12
on ground-water recharge, 194
on limestone, 197
and Wenzel, L. K., on ground water, 192
Meinzer unit, 655
Meixner, H., on ionic groupings, 814
Mellen, F. F., on Betheden zone, Miss., 848
Melnikovite, 362
Memorials—
Cumings, W. L. (Spencer), 99
Holden, R. J. (Bevan), 186
Kummel, H. B. (Johnson), 99
Meneghinite, 114, 554
Mercury, China, 404, 447
Italy, Idria deposits, 31
ore deposition, 35
U. S., supplies in wartime, 318
Merwin, H. E., on calcite, 496
Metallurgy, nonferrous (review), 284
Metals, humic acid experiments, 50
ionic radii and deposition, 42
Metamorphic rocks, color chart, 853
Metamorphism, iron deposits, China, 429
Malånäs district, Sweden (review), 668
Messina district, Union South Africa (review), 769
quartz crystal deposits, Ark., 600
Mexico, Pachuca area, structure (discussion), 77
Meyer, C., *Notes on the cutting and polishing of thin sections*, 166–172
Mica, China, 467
frequency count technique, 756
U. S., supplies in wartime, 319
Michigan copper district, Recent contributions to the geology of the (Broderick, Hohl, and Eidemiller), 675
Micro-pseudomorphism, Some notes on (Schouten), 348, 529
Microscopic characters of vein carbonates (Grout), 475
Mielenz, R. C., and Okeson, C. J., *Foundation displacements along the Malheur River siphon as effected by swelling shale*, 266–281
Military and scientific cooperation, 390
Miller, L. W., analyses by, 228
Milligan, G. C., with Douglas, G. V., and Goodman, N. R., *On the nature of replacement*, 546–553
Mineral resources (discussion), 851
Missouri Valley, maps (review), 285
Mineral resources of China (Juan), 399
Mineralization, alunite deposits, Utah, 640
copper, Castle Dome area, Ariz., 823
Michigan, 688, 701
Pachuca area, Mexico (discussion), 80
quartz, Goiaz, Brazil, 798
vein mineral paragenesis, 61
zinc ore, Jefferson City area, Tenn., 162
Mineralization Axis, 701
Mineralization in the Clark Fork district, Bonner County, Idaho, Lead-silver (Anderson), 105
Mineralization in the San Juan Mountains, Colorado, as shown at the Dunmore mine, Ouray County, Colorado, Stages and epochs of (Kelley and Silver), 139
Mineralizing solutions in the Picher field, Oklahoma-Kansas, Movement of (Stoiber), 800
Mineralogy, bauxite deposits, 68
Castle Dome copper deposit, Ariz., 823
dunhamite and monteponite, 767
identification cards, 761
iron minerals in clays, 137
lead-silver, Clark Fork district, Idaho, 108
Malånäs district, Sweden (review), 669
Minerals, Humic acids and true organic acids as solvents of (Fetzer), 47
I. Introduction, Transport and deposition of the non-sulphide (Smith), 57
The punched card identification of ore (Fairbanks), 761
Wartime dependence on foreign (Bateman), 308
copper, Michigan deposits, 700, 711
iron minerals in clays, 137
specific weights, 752
Minerals in polished sections, Luminescent phenomena as aides in the localization (Yagoda), 813
Mining, Canada, handbook (review), 855
India (review), 91
pyrite, Missouri (review), 91
quartz deposits, Goiaz, Brazil, 777
tungsten, China, 438
Mining geology (review), 670

Miser, H. D., on Ouachita deformation, 618
on quartz, 599
on shales, 600
Mississippi, aluminous clays, 841
Missouri, pyrite (review), 88
Missouri Valley, mineral resource maps (review), 285
Mitchelson, A. T., and Mucket, D. C., on ground water, 196
Molybdenite, 437, 440, 823
Molybdenum, China, 440
Monazite, 60, 62
Montana, chromite, Stillwater Complex, 214
clays, Whiteware deposit, 137
Monteponite, Sardinia, 767
Montmorillonite, 70
Moon, physiography (review), 556
Moore, E. S., and Maynard, J. E., on iron, 54
Morey, G. W., and Ingerson, E., on quartz, 59
Morgan, G. D., on Ouachita deformation, 618
Morocco, Tin and tungsten deposits of French (Heck), 383
Morris, J. M., on tin, 443
Morse, H. N., on solutes, 17
Mud flows, New Zealand, 333
Müller, W. J., and Königsberger, J., on orthoclase, 59
Munsell color designations for rocks, 854
Murayama, K., on copper, 452
Murdoch, J., on ore identification, 763
Murray, J., and Irvine, R., on sulphates, 235
Muscovite, synthesis, 59
Museums, restoration plea (communication), 175

Namaqualand, copper deposits, 37
National Research Council, Division of Geology and Geography, report, 97
Native antimony, 497, 498
Natroalunite, 629
Natural resources (review), 671
Nebraska, ground water, Platte River valley, 193
Nelson, R. A., with Hendricks, S. B., and Goldich, S. S., *A portable differential thermal analysis unit for bauxite exploration*, 64–76
Nelsonite, Piney River ilmenite area, Va., 745
Netherlands East Indies, electrum pseudomorphs after marcasite, Bantam, 381
Newhouse, W. H., on silica, 612
on solutions, 34, 801
New Jersey, Artificial recharge of productive ground-water aquifers in (Barksdale and Debuchananne), 726
New York, Artificial recharge of ground water on Long Island (Brashears), 503
New Zealand, Landslides and their relation to engineering in the Dunedin district (Benson), 328
Newman, M. H., on zinc, 160
New Mexico, dunhamite, Organ Mtns., 767
Nickel, 43
China, 404, 441
replacement in ores, 661
U. S., supplies in wartime, 320
Niggli, P., on orthoclase, 59
Nisida, S., on oil shale, China, 424
Noble, W. M., analysis by, 238
Noll, W., on muscovite, 59
Nontronite, 70
Northup, M. A., and Lee, O. I., on mineral luminescence, 816
Norway, nickel ores, pseudomorphic structures, Evje, 381
Nova Scotia, slates, replacement tests, 547

Oder, C. R. L., and Miller, H. W., on Jefferson City area, Tenn., 161
Ogura, T., on lead, 453
Ohio, ground water, Cincinnati region, 194
Oil shale, China, 402, 422
Okeson, C. J., with Mielenz, R. C., *Foundation displacements along the Malheur River siphon as effected by swelling shales*, 266–281
Oklahoma, quartz crystals, McCurtain Co., 599
Oklahoma-Kansas, Movement of mineralizing solutions in the Picher field, (Stoiber), 800
Oliveria, A. I., and Leonardos, O. H., on schists, 776
O'Neil, T. F., on gibbsite, 260
Ontario, Kirkland Lake area, ore barriers, 34, 37
Little Long Lac, porphyry (discussion), 282
replacement in arsenide ores, 661
Oolites, iron in bauxite, Ore., 254
Opacity identification of minerals, 765
Ordway, R. J., books received, 92, 178, 286, 393
Ore bodies, The rôle of sulphur bacteria in the formation of the so-called sedimentary copper ores and pyritic (Schouten), 517
alunite, White Horse area, Utah, 639
quartz deposits, Goiaz, Brazil, 776, 781, 793
Ore bodies in the Jefferson City area, Tennessee, Structural control of (Brokaw and Jones), 160
Ore deposition, The control of impounding structures on (Mackay), 13
Ore deposits (review), 670
China, 399
chromite types, 208
copper, Michigan district, 675
Dunmore mine, San Juan Mtns., Colo., 139

Ore deposits—Continued
structure and ore deposition, 13
titanium, Va., 738
vein mineral paragenesis, 61
Ore minerals, The punched card identification of (Fairbanks), 761
Ore shoots, copper, Michigan, 688
Dunmore mine, Colo., 139
Ore-forming solutions, 26
Ore-genetic studies, Synthetic replacements as an aid to (Schouten), 659
Oregon, Ferruginous bauxite deposits in northwestern (Libbey, Lowry, and Mason), 246
chromite, composition, 214, 216
clays, Molalla and Hobart Butte deposits, 128, 130
Malheur River siphon, displacements, 266
Ores, bauxite, Oregon, 253
carbonates and ore minerals, 496
Dunmore mine, Colo., 139
gel structures, 370
source (discussion), 173
zinc, Jefferson City area, Tenn., 162
Ores and pyritic ore bodies, The rôle of sulphur bacteria in the formation of the so-called sedimentary copper (Schouten), 517
Organic acids as solvents of minerals, Humic acids and true (Fetzer), 47
Origin, bauxite, Oregon, 259
copper deposits, Mich., 710
copper-tungsten ore, Dunmore mine, Colo., 154
kaolin deposits, Clarksburg district, Tenn., 848
quartz deposits, Ark., 616
Orpiment, 450
Orthoclase, 59
Osmosis, 14
Ostwald, W., and Rödiger, W., on humic acid, 49
Ouachita deformation, age, 619
Overgrowths, lead-zinc minerals, 804
Oxidation, Clark Fork district, Idaho, 107
micro-pseudomorphs, 357
pyrite deposits, Missouri (review), 90

Paige, S., discussion by, 853
Palache, C., on calcite, 482
on mineral luminescence, 816
et al., communication by, 175
on meneghinite, 554
on tarnishing reactions, 763
Papenfus, E. B., on valleriite, 767
Paragenesis, ilmenite ore, Va., 743
lead-silver ores, Clark Fork, Idaho, 120
ores, Dunmore mine, Colo., 151
pyrite deposits, Missouri (review), 90
quartz deposits, Ark., 612
sequence of carbonates, 493
sulphide ores, 534
vein minerals, 61
Pardee, F. G., on faults, 703
Patton, M. L., coal industries (review), 671
Peacock, M. A., on pyrite, 553
Peat, humic acid extraction, 48
Pegmatite, elements in vein minerals, 60
tungsten deposits, China, 437
Peterson, N. P., Gilbert, C. M., and Quick, G. L., *Hydrothermal alteration in the Castle Dome copper deposit, Arizona,* 820–840
Petretic, G. J., analysis by, 238
Petroleum, bibliography (review), 285
China, 402, 419
dehydration in reservoirs, 45
formation, hydrobacteriology (review), 558
United States, resources (review), 92
Phosphates (review), 393
China, 467
Phosphorescence of minerals, 816
Photomicrographs—
anorthite, Cuba, 204
gibbsite and basalt, Oregon, 263
huebnerite, Dunmore mine, Colo., 150
latite, Marysvale, Utah, 624
lead-silver ore, Clark Fork, Idaho, 118
micro-pseudomorphs, 350
ores and rocks, Piney River, Va., 742
petrified wood, Nova Scotia, 547
polished thin section, 171
scheelite, 816
sulphide ore structures, 522
sulphides, replacement, 660
volcanics and kaolinite, 126, 135
Physiography, moon (review), 556
Picher field, Oklahoma-Kansas, Movement of mineralizing solutions in the (Stoiber), 800
Pilcher, R. B., *et al.*, review of book by, 769
Piney River, Virginia, Notes on the ilmenite deposit at (Davidson, Grout, and Schwartz), 738
Piper, A. M., *et al.*, on ground water, 193
Placers, quartz crystals, Calif., 598
tungsten deposits, China, 438
Plans, Malheur River siphon, Ore., 268
Piney River ilmenite property, Va., 740
projection of planes, 544
quartz workings, Goiaz, Brazil, 791
White Horse alunite deposit, Utah, 634
Platts, J. B., on carbonates, 494, 499
Plauchud, E., on sulphate reduction, 235
Plerotic water, 2
Pneumatolysis, 41
Pogue, J. E., petroleum, capital invested (review), 92
Polished sections, Luminescent phenomena as aides in the localization of minerals in (Yagoda), 813
Polishing of thin sections, Notes on the cutting and (Meyer), 166
Polthins, 170
Potamology, 2

Powers, S., on Ouachita deformation, 618
Pratt, W. E., petroleum, reserves (review), 92
Price, P., on Noranda mine, Que., 32
Proctor, P. D., with Willard, M. E., *White Horse alunite deposit, Marysvale, Utah*, 619–643
Proctor, R. V., review of book by, 557
Prospecting (review), 670
  bauxite, thermal analysis unit, 64
  clays, Clarksburg district, Tenn., 846
  quartz deposits, Goiaz, Brazil, 777
Proustite, 58
Pseudo-connate water, 221
Pseudomorphs, 546
  bornite after pyrite, 523
  carbonate, 490
  cervantite after stibnite, 446
  limonite after pyrite, Brazil, 793
  micro-pseudomorphs, 348, 529
  sulphide minerals, 659
Purington, C. W., on carbonates, 481
  on mineralization, San Juan Mtns., Colo., 157
Putnam, W. S., and Sharp, R. P., on earthflows, 334
Pyrargyrite, 119
Pyrite, 43, 110, 120, 136, 147, 162, 349, 374, 445, 449, 450, 452, 497, 660, 669, 743, 793, 798
  Castle Dome copper deposit, Ariz., 820
  China, 405, 458
  Cyprus, Skouriotissa deposit, 32
  Missouri (review), 88
  replacement, 548
Pyritic ore bodies, The rôle of sulphur bacteria in the formation of the so-called sedimentary copper ores and (Schouten), 517
Pyrophyllite, China, 466
Pyrrhotite, 354, 497, 523, 660

Quartz, 71, 108, 111, 113, 120, 144, 148, 383, 445, 449, 452, 461, 491, 831
  China, 467
  Missouri (review), 89
  synthesis, 59
  U. S., supplies in wartime, 319
Quartz crystal deposits in the State of Goiaz, Brazil (Campbell), 773
Quartz crystal deposits of western Arkansas (Engel), 598
Quebec, Noranda mine, structure, 32
Queensland, Mount Isa, micro-pseudomorphs in ores, 348
Quick, G. L., Peterson, N. P., with Gilbert, C. M., *Hydrothermal alteration in the Castle Dome copper deposit, Arizona*, 820–840

Ralston, O. C., on mineral conditioning, 754
Ramdohr, P., on inclusions, 369
Ransome, F. L., on calcite, 494
  on pseudomorphs, 490
  on Globe Quadrangle, Ariz., 820
  and Calkins, F. C., on Coeur d'Alene region, Idaho, 105
  on siderite, 488
Rasor, C. A., on mineral identification, 762
Rastall, R. H., on colloids, 26
Realgar, 450
Recharge of artesian limestone at Orlando, Florida, Artificial (Unklesbay and Cooper), 293
Recharge of glacial sand and gravel with filtered river water at Louisville, Kentucky, Artificial (Guyton), 644
Recharge of ground water on Long Island, New York, Artificial (Brashears), 503
Recharge of productive ground-water aquifers in New Jersey, Artificial (Barksdale and Debuchananne), 726
Rectorite, 613
Reflectivity of minerals, 765
Reid, J. A., discussion of paper by, 282
Renick, B. C., on sulphate reduction, 234
Replacement, On the nature of (Douglas, Goodman, Milligan), 546
  carbonate veins, 489
  ilmenite, Piney River, Va., 738
  sulphides and carbonates, 534
Replacements as an aid to ore-genetic studies, Synthetic (Schouten), 659
Rettger, R. E., on bauxite, 848
Reviews—
  Bibliography on the petroleum industry (DeGolyer and Vance), 285
  Canadian Mines Handbook—1946 Edition, 855
  Earth and the State, a study of political geography (Whittlesey), 177
  English-French and French-English technical dictionary (review), 670
  Features of the moon—Geology applied to selenology (Spurr), 556
  Geology and ores of the Malånäs district, Västerbotten, Sweden (Gavelin), Gilluly, 668
  Geology as a profession (Taylor), 557
  Geology of the Messina copper mines and surrounding country (Söhnge), 769
  German for the scientist (Wiener), 558
  Guidebook to the geology of Utah, No. 1—Geology and geography of the Henry Mountain region (Hunt), 556
  Handbook of nonferrous metallurgy (Liddell), 284
  Indian mining (Dunn), 91
  Marine microbiology: A monograph on hydrobacteriology (ZoBell), 558
  Mineral resources of the Missouri Valley region (Dow, Larrabee, and Clabaugh), 285
  Our oil resources (Fanning, *et al.*), 92
  Our "Vanishing" natural resources—a symposium, 671

Reviews—Continued
Phosphates and superphosphates (Gray), 393
Principes de Geologie, 2nd ed. (Fourmarier), 855
Principles of field and mining geology (Forrester), 670
Pyrite deposits of Missouri (Grawe), Brown, 88
Rock tunneling with steel supports (Proctor and White), 557
Rocks and rivers (Shuler), 91
Science in a changing world (Cable, Getchell, and Kadesch), 284
Uranium and atomic power (De Ment and Dake), 91
Volcanoes declare war (Jaggar), 177
What industry owes to chemical science—a symposium (Pilcher, *et al.*), 769
Rhodochrosite, 112, 147, 154
Richert, J. G., on ground water, 192
Rickard, T. A., on veins, 477
Riffenburg, H. B., analyses by, 228
River water at Louisville, Kentucky, Artificial recharge of glacial sand and gravel with filtered (Guyton), 644
Rivers, ground-water recharge, 195
Rivers and rocks (review), 91
Roberts, J. K., and Collins, R. L., on Ackerman formation, 844
Rock slides, 330
Rocks, Preliminary chemical correlation of chromite with the containing (Thayer), 202
color chart (communication), 853
Hales Bar damsite, Tenn., 592
Rocks and rivers (review), 91
Rocks and tunneling (review), 557
Rogers, A. F., on carbonates, 480
Rogers, G. S., on sulphate reduction, 235
Roper, R. M., on ground water, 733
Ross, C. S., kaolinite determination by, 628
on base exchange, 233, 241
on carbonates, 478, 498
on ilmenite, 738
on magmas, 747
on montmorillonite, 829
Rudy, R. B., analysis by, 228
Ruler for simplifying the graphic solution of problems in structural geology, A cotangent (White), 539
Russell, C., on slumping, 335
Rutile, 60, 62

Sack pockets, quartz, Ark., 612
Sagui, C. L., discussion by, 851
on economic liberalism, 851
Sahama, T., on fragmental analysis, 758
Sakamoto, T., on oil shale, China, 424
and Matuda, K., on oil shale, China, 424
Salt, China, 469
Salt domes, formation, 45
Saltpeter (sodium nitrate), China, 469
Sampling (review), 670
Sampson, E., on chromite deposits, 208
San Juan Mountains, Colorado, as shown at the Dunmore mine, Ouray County, Colorado, Stages and epochs of mineralization in the (Kelley and Silver), 139
Sand and gravel with filtered river water at Louisville, Kentucky, Artificial recharge of glacial (Guyton), 644
Sandberg, A. E., on Keweenawan stratigraphy, 680
Sandell, E. B., and Goldich, S. S., on differentiation, 686, 714
Sanford, S. T., on ground water, 239
Sawai, T., and Haraguti, K., on oil shale, China, 424
Schachtschabel, F., on bivalent bases, 233
Schaller, W. T., on calcite, 482
on carbonates, 501
Scheelite, 60, 383, 437, 814
Schlaepfer, M., and Niggli, P., on orthoclase, 59
Schmidt, L. A., Jr., on grouting, 587
Schneiderhöhn, H., on mineral identification, 762
on pyrite, 517
and Ramdohr, P., on ore identification, 763
Schnellman, G. A., on Halkyn area, England, 36
on ponds, 24
Schouten, C., *The rôle of sulphur bacteria in the formation of the so-called sedimentary copper ores and pyritic ore bodies*, 517–538
Some notes on micro-pseudomorphism, 348–382, 529
Synthetic replacements as an aid to ore-genetic studies, 659–667
on intergrowths, 663
on micro-pseudomorphs, 348
on replacement, 659
on sulphides, 517, 659
Schuette, C. N., on mercury deposition, 35
on traps, 24
Schwartz, G. M., on carbonates, 491, 496, 498
on mineral identification, 762
and Sandberg, A. E., on felsites, 709
with Davidson, D. M., and Grout, F. F., *Notes on the ilmenite deposit at Piney River, Virginia*, 738–748
Science (review), 284
Scientific and military cooperation, 390
Scientific notes and news, 101, 188, 290, 398, 564, 673, 770, 859
Scorodite, 136
Seaman, A. E., and Seaman, W. A., on Keweenawan series, 680
Seaman, W. A., on faults, 680
Secrist, M. H., on carbonates, 481
Sections—
Dunedin district, New Zealand, 332
Dunmore lode, Colo., 145

Sections—Continued
Hales Bar damsite, Tenn., 580
Ione area, Calif., 125
Malheur River siphon, Ore, 274
Michigan copper district, 678
Ohio River channel, Louisville, Ky., 656
Orlando area, Florida, 295
Pearl vein, Clark Fork district, Idaho, 107
quartz crystal deposits, Arkansas, 601
Goiaz, Brazil, 787
Raibl Valley, Italy, 30
White Horse alunite deposit, Utah, 635
Sections, Luminescent phenomena as aides in the localization of minerals in polished (Yagoda), 813
Sedimentary and volcanic processes in the formation of high alumina clay (Allen), 124
Sedimentary copper ores and pyritic ore bodies, The rôle of sulphur bacteria in the so-called (Schouten), 517
Sedimentation, hydrobacteriology (review), 558
Sediments, arkose or porphyry, Little Long Lac, Ont., 282
clays, Clarksburg region, Tenn., 841
Coastal Plain, Va., 219
color chart, 853
iron, China, 429
Michigan copper area, 689
silt in recharge basins, N. J., 726, 736
Seidell, A., on acid, 53
Selenology (review), 556
Sellards, E. H., on ground water, 294
on spouting wells, 305
and Gunter, H., on wells, 294
Semseyite, 114, 554
Sénarmont, H. de, on sulphides, 58
Sericite, 108, 831
Shale, analyses, Hales Bar damsite, Tenn., 592
Shand, S. J., on magmatic action, 746
Shannon, E., on galenobismutite, 554
Sharpe, C. F. S., on landslides, 330
Shaw, S. F., review of bibliography by, 285
Shearer, H. K., and de Souza, H. C. A., on schists, 776
Short, M. N., on lead-silver minerals, 113
on mineral identification, 554
on tarnishing reactions, 761
Shuler, E. W., review of book by, 91
Siderite, 71, 108, 111, 120, 136, 429
Sideroplesite, 495
Silicification, 45, 613
chromite deposits, 207
Sills, Castle Dome area, Ariz., 825
Silver, 42
China, 403, 454
Clark Fork district, microscopy, Idaho, 554
humic acid experiments, 52
Mexico, Pachuca area (discussion), 77
replacement in ores, 661
Silver, C., with Kelley, V. C., *Stages and epochs of mineralization in the San Juan Mountains, Colorado, as shown at the Dunmore mine, Ouray County, Colorado,* 139–159
Silver mineralization in the Clark Fork district, Bonner County, Idaho, Lead (Anderson), 105
Singewald, J. T., Jr., on native copper, 712
Sink holes, Missouri (review), 88
Siphon as effected by swelling shales, Foundation displacements along the Malheur River (Mielenz and Okeson), 266
Slates, Nova Scotia, replacement tests, 547
Slickensides, alunite, Utah, 633
clays, Hobart Butte, Ore., 130, 132
Hales Bar damsite, Tenn., 591
quartz, Ark., 615
Smith, E. S. C., and Parsons, W. H., on mineral luminescence, 816
Smith, F. G., *Transport and deposition of the non-sulphide vein minerals. I. Introduction,* 57–63
on sulphides, 58
Smith, W. T., on carbonates, 478
Society of Economic Geologists, 97, 180, 397, 562
Soda (sodium carbonate), China, 469
Sodium carbonate (soda), China, 469
Sodium nitrate (saltpeter), China, 469
Söhnge, P. G., review of memoir by, 769
Soils, fat clays, 272
lateritic soil, thermal analysis, 74
moisture of soils, 2
Solutions in the Picher field, Oklahoma-Kansas, Movement of mineralizing (Stoiber), 800
Solvents of minerals, Humic acids and true organic acids as (Fetzer), 47
Sorby, H. C., on inclusions, 174
Sosman, R. B., on quartz, 607
Specific gravity and volume differences in fragment analysis, A correction factor for (Chayes), 749
Spectroscopy, pyrite ores, Missouri (review), 91
Specularite, 799
Speil, S., *et al.,* on thermal analysis, 65
Spencer, A. C., memorial by, 99
Sphalerite, 109, 162, 351, 366, 374, 452, 455, 496, 522, 660, 804, 817
Spinel, 202, 207
Spodumene, 60, 62
Spouting wells, 305
Springs, Louisville area, Ky., 648
Spurr, J. E., on breccias, 477
on calcite, 497
on ores, 38, 39
review of book by, 556
Stains, carbonate identification, 478
Stannite, 366
Stearns, H. T., *et al.,* on ground water, 193
Sterry-Hunt, J., on dolomite, 59

Stevens, R. E., on chromite, 205
Stewart, D. R., *et al.*, on bauxite, 849
Stibnite, 445, 449, 497
Stillwell, F. L., on replacement, 666
Stockpiles of minerals, 325
Stoiber, R. E., *Movement of mineralizing solutions in the Picher field, Oklahoma-Kansas*, 800–812
Stratigraphy, bauxites, Oregon, 249
  Clarksburg area, Tenn., 842
  Coastal Plain, Va., 219
  Cowlitz clay deposit, Wash., 127
  Dunmore mine area, San Juan Mtns., Colo., 140
  Florida, Orlando district, 295
  Hales Bar damsite, Tenn., 587
  Jefferson City area, Tenn., 161
  Long Island, N. Y., 506
  Marysvale district, Utah, 621
  Michigan copper district, 679
  Picher field, Okla.-Kan., 808
Stringfield, V. T., on ground water, 294
  on wells, 300
Stromeyerite, 663
Strontianite, 60, 62
Structural geology, A cotangent ruler for simplifying the graphic solution of problems in (White), 539
Structure (review), 670
  barriers to ore-forming solutions, 24
  Castle Dome area, Ariz., 823
  Columbia River basalt, Ore., 251
  Dunedin district, New Zealand, 329
  Dunmore mine area, Colo., 142
  ground water recharge and aquifers, 194
  Hales Bar damsite, Tenn., 590
  Malånäs district, Sweden (review), 668
  Marysvale district, Utah, 622, 632
  Mexico, Pachuca area (discussion), 77
  Picher field, Okla.-Kan., 809
  pyrite deposits, Missouri (review), 88
  quartz crystal region, Arkansas, 600
  Goiaz, Brazil, 780, 783
  Utah, Henry Mtns. (review), 556
Structures on ore deposition, The control of impounding (Mackay), 13
Sulphides, bacteria and ore formation, 517
  Clark Fork district, Idaho, 108, 114, 120
  Malånäs district, Sweden (review), 668
  micro-pseudomorphs, 348
  Piney River ilmenite deposit, Va., 743
  pyrite deposits, Missouri (review), 88
Sulphur bacteria in the formation of the so-called sedimentary copper ores and pyritic ore bodies, The rôle of (Schouten), 517
Sun, C. C., on oil, China, 423
Superphosphates (review), 393
Surinam, bauxite, thermal analysis, 67
Sweden, Malånäs district (review), 668
Swelling shales, Foundation displacements along the Malheur River siphon as effected by (Mielenz and Okeson), 266
Switzer, J. A., on grout, 581
Synthesis, vein minerals, 58
Synthetic faults, 85
Synthetic replacements as an aid to ore-genetic studies (Schouten), 659

Taber, S., on veins, 485
Tables—
  analyses, chromite, 205, 215
  clays, Hobart Butte, Ore., 132
  latite, Marysvale, Utah, 623
  monzonites, Castle Dome area, Ariz., 836
  rocks, Hales Bar damsite, Tenn., 592
  waters, Coastal Plain, Va., 222
  bauxite and laterite, analyses, 74
  carbonates, indices and specific gravities, 479
  China, mineral resources, 405, 467
  electrolytes, osmotic pressure, 16
  fragment analysis, 751, 753
  ground water consumption, Louisville, Ky., 648
  metals dissolved by humic acid, 53
  pipeline movements, New Zealand, 331
  quartz crystals, Ark., 599
  replacement of slates, 548
  soils, Malheur River siphon, Ore., 277
  stratigraphy, Castle Rock, Wash., 127
  Dunmore mine area, Colo., 141
  Eocene, west Tenn., 843
  Hales Bar damsite, Tenn., 588
  Michigan copper district, 679
  sulpho minerals, etch reactions and polarization colors, 114
Taggart, A. F., on mineral conditioning, 754
Talc, China, 466
Talmage, S. B., on breccias, 477
Tantalite, 60, 62
  U. S., supplies in wartime, 320
Tarnishing reactions of minerals, 763
Tarr, W. A., on calcite, 495
Taylor, A. R., review of booklet by, 557
Taylor, D. W., on arcs of rupture, 343
Technique, asphalt grouting, Tenn., 583
  bauxite, thermal analysis unit, 64
  carbonates, identification, 477
  color chart for rocks (communication), 853
  fluorescence and luminescence of minerals, 814, 817
  fragment analysis, 751
  mineral identification cards, 761
  thin sections, cutting and polishing, 166
Tegengren, F. R., on iron, 424, 433
Teixeria, E. A., on bauxite, 575
Telescoped ore deposits, 38
  Dunmore mine, Colo., 158
Tennantite, 452
Tennessee, Clarksburg kaolin area of Carroll County (Whitlatch and Gildersleeve), 841

Tennessee—Continued
Structural control of ore bodies in the Jefferson City area (Brokaw and Jones), 160
Hales Bar Dam foundation, 576
Terry, L. F., natural gas reserves, U. S. (review), 92
Terzaghi, K., review of book by, 557
Tetrahedrite, 109, 119, 154, 367, 452
Texas, ground water, Houston area, 195
Thayer, T. P., *Preliminary chemical correlation of chromite with the containing rocks*, 202–217
on chromite, 204
Thermal analysis unit for bauxite exploration, A portable differential (Hendricks, Goldich, and Nelson), 64
Thiel, G. A., on sulphate reduction, 235
Thin sections, Notes on the cutting and polishing of (Meyer), 166
Thomas, H. E., on ground water, 193
Thompson, D. G., on ground water, 196
and Klaer, F. H., Jr., on ground water, 194
et al., on Long Island, N. Y., 506
Thompson, G. A., discussion by, 173
Thomson, R. M., x-ray study by, 553
Thornburg, C. L., discussion of paper by, 77
Thorp, T. E., on cations, 21
Tibbets, F. H., on flood water, 197
Tin, China, 403, 442
ore deposition and structure, 38
U. S., supplies in wartime, 321
Tin and tungsten deposits of French Morocco (Heck), 383
Titanite, 60
Todd, E. W., on gold, 34, 37
Torbernite, 814
Torgasheff, B. P., on coal, 415
Tourmaline, 60, 62
Tracey, J. I., Jr., with Goldman, M. I., *Relations of bauxite and kaolin in the Arkansas bauxite deposits*, 567–575
Transport and deposition of the non-sulphide vein minerals. I. Introduction (Smith), 57
Transvaal, chromite, Bushveld Complex, 214
Treasher, R. C., on Boring lava, Ore., 251
Tungsten, China, 402, 436
Dunmore mine, Colo., 144
U. S. supplies in wartime, 322
Tungsten deposits of French Morocco, Tin and (Heck), 383
Tunneling (review), 557
Tunnels, Dunedin district, New Zealand, 340
Turner, F. J., on schistosity, 328
Turner, H. W., on Ione formation, Calif., 125
Turner, S. F., *et al.*, on ground water, 193
Twenhofel, W. H., and Tyler, S. A., on carbonates, 478
Twinning, carbonates, 483
quartz, 608

Ulrich, R. N. F., memorial of, 562
Ultrafiltration, 14, 16
Umpleby, J. B., on Osborn fault, Idaho, 106
and Jones, E. L., Jr., on silver, 106
Underground water, solution of limestone (review), 88
Union South Africa, copper, Messina district (review), 769
United States, minerals, wartime supply, 308
petroleum (review), 92
Unklesbay, A. G., and Cooper, H. H., Jr., *Artificial recharge of artesian limestone at Orlando, Florida*, 293–307
on limestone, 197
Unmixing, 365
Uranium and atomic power (review), 91
Uranophane, 819
Utah, White Horse alunite deposit, Marysvale (Willard and Proctor), 619
ground water, Ogden supplies, 193
Henry Mtns. (review), 556
Utino, T., and Okada, S., on copper, 452
Uwatoko, K., on oil shale, China, 424

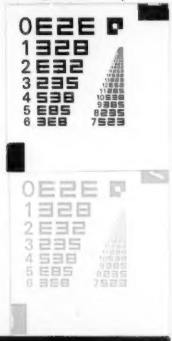
Valleriite, 767
Vanadium, U. S., supplies in wartime, 321
Vance, H., review of book by, 285
Van der Veen, R. W., on sulphides, 661
Van der Walt, C. F. J., on chromite, 208
Van Hise, C. R., and Leith, C. K., on greenstone, 683
Vein carbonates, Microscopic characters of (Grout), 475
Vein minerals. I. Introduction. Transport and deposition of the non-sulphide (Smith), 57
Veins, copper, Castle Dome deposit, Ariz., 820
Messina district, Union South Africa (review), 769
Dunmore mine, Colo., 139
Mexico, Pachuca silver area (discussion), 78
quartz, Arkansas, 609
Goiaz, Brazil, 773
tin-tungsten, Morocco, French, 384, 388
tungsten, China, 437
Venezuela, chromite, Paraguana Peninsula, 214
Veterans' retraining (communication), 86
Virginia, Genesis of ground waters in the Coastal Plain of (Cederstrom), 218
Notes on the ilmenite deposit at Piney River (Davidson, Grout, and Schwartz), 738
Voigt, V., on sediments, 476
Volcanic processes in the formation of high alumina clay, Sedimentary and (Allen), 124

Volcanoes (review), 177
Volume differences in fragment analysis, A correction factor for specific gravity and (Chayes), 749
Von Diestite, 766
Vugs, 485
gypsum and anglesite lined, 667
quartz veins, Ark., 610

Wackenröder, —., on humic acid, 48
Waksman, S. A., on sulphate reduction, 235
Walker, T. L., and Parsons, A. L., on calcite, 502
Wandke, A., and Moore, T. G., on aragonite, 500
Wartime dependence on foreign minerals (Bateman), 308
Washburne, C. W., on Idaho formation, Ore., 271
Washington, clays, Cowlitz deposit, 126
Water, economic geology relationships, 1
Watson, E. De P., on sulphides, 487
Watson, T. L., and Taber, S., on nelsonites, 745
Weathering, clays, Hobart Butte, Ore., 135
Hales Bar damsite, Tenn., 592
nepheline syenite, Ark., 567
Weaver, C. E., on Columbia River basalt, 251
Weibullite, 766
Weller, S., on carbonates, 495
Wells, F. G., on Ackerman formation, 844
and Waters, A. C., on siderite, 483
Wells, Louisville area, Ky., 644
Orlando area, Florida, 298
recharge and water supply, 192
recharge types, Long Island, N. Y., 509
recharge wells, New Jersey, 726
salt wells, China, 470
spouting wells, 305
Wenzel, L. K., and Lugn, A. L., on water supplies, 193
White, C. H., discussion of paper by, 173
White, T. L., review of book by, 557
White, W. H., on carbonates, 484, 497
White, W. N., *et al.*, on ground water, 195
White, W. S., *A cotangent ruler for simplifying the graphic solution of problems in structural geology*, 539–545
White Horse alunite deposit, Marysvale, Utah (Willard and Proctor), 619
Whitlatch, G. I., on Ackerman formation, 844
and Gildersleeve, B., *Clarksburg kaolin area of Carroll County, Tennessee*, 841–850
Whittlesey, D., review of book by, 177
Wiener, P. F., review of book by, 558
Wilkinson, W. D., *et al.*, on Troutdale formation, Ore, 251
Willard, M. E., on bournonite, 110
and Proctor, P. D., *White Horse alunite deposit, Marysvale, Utah*, 619–643
Willemite, 817
Willis, B., and Willis, R., on mapping methods, 539
Wilson, H., and Treasher, R. C., on alumina, 260
on clays, 128
Wilson, R. E., oil refining technology (review), 92
Winchell, A. N., on carbonates, 476
Wisser, E., discussion by, 77
on gold, 37
on Pachuca area, Mexico, 77
Witherite, 60, 62
Wolfachite, 767
Wolff, F. von, on sulphides, 535
Wolframite, 60, 62, 383, 437, 442
Wolfsbergite, 767
Wong, W. H., and Hou, T. F., on manganese, 436
Woods, T. S., on copper, 694
Wright, F. J., on calcite, 497

X-ray studies, clay, Hobart Butte, Ore., 131
pyrite, 548
sulphide ores, Missouri (review), 91

Yagoda, H., *Luminescent phenomena as aides in the localization of minerals in polished sections*, 813–819
on trace constituents, 819
on uranophane, 819
and Donahue, D. D., on ultraviolet illuminator, 814
Yugoslavia, lead-zinc, Mezica (Meisa) deposit, 29

Zaruba, Q., memorial by, 562
Zeolites, 711
Zies, E. G., on titanium, 746
Zinc, China, 403, 454
humic acid experiments, 52
Jefferson City area, Tenn., 160
Picher district, solution movement, 800
Sweden, Malånäs district (review), 669
U. S., supplies in wartime, 322
Yugoslavia, Mezica deposit, 29
Zircon, 60
ZoBell, C. E., review of monograph by, 558
Zoned crystals, carbonate, 482
Zoning, copper, Michigan, 692
lead-silver ores, Clark Fork, Idaho, 122
Messina copper district, Union South Africa (review), 769
metamorphism, Malånäs district, Sweden (review), 668
rock alteration, 44
Zsigmondy, R., on particle sizes, 19

C15